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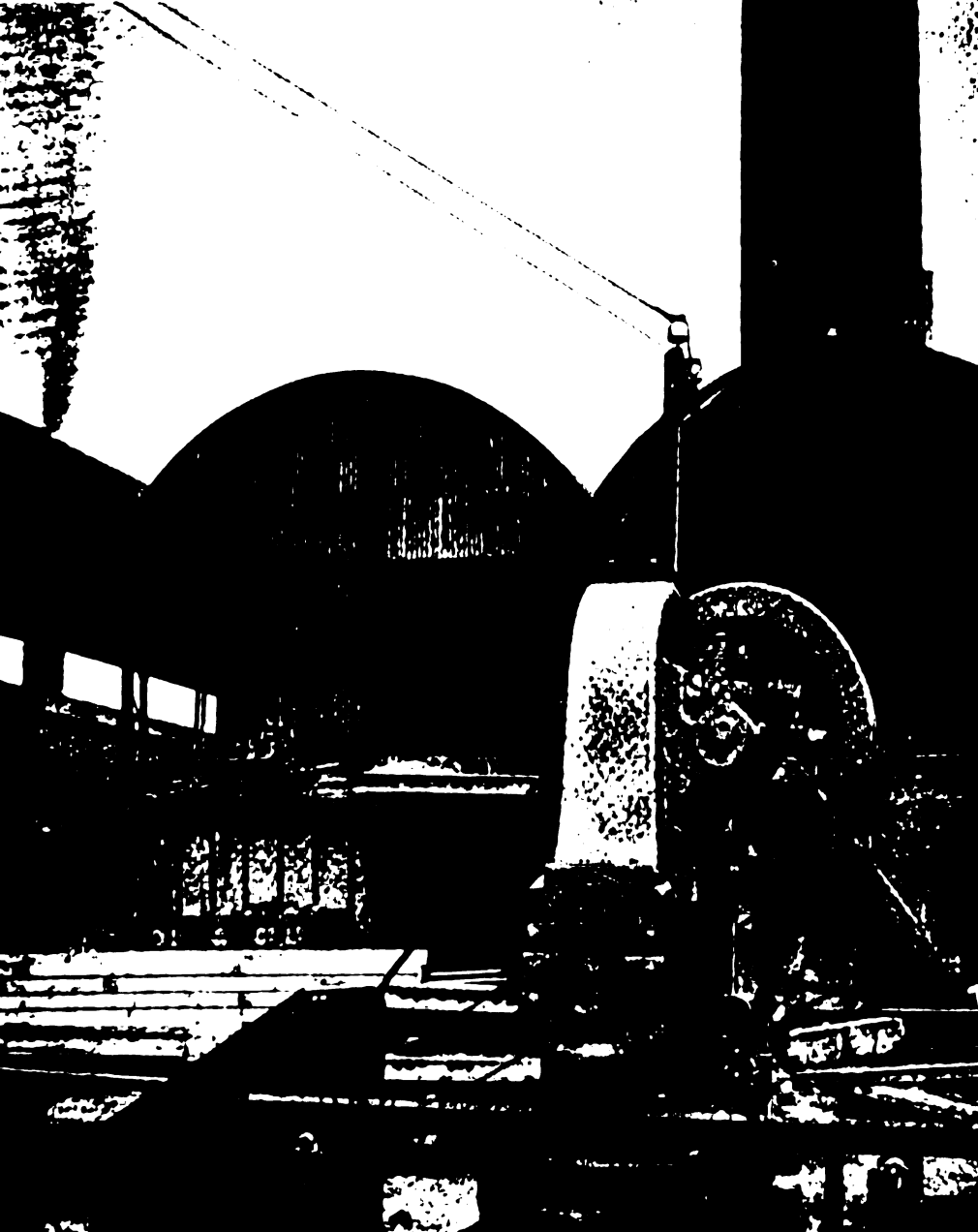
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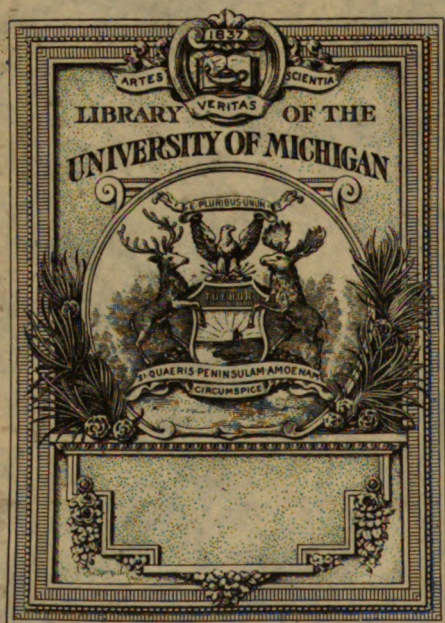
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1894

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THE IRON AND STEEL INSTITUTE.

SECTION I. *MINUTES OF PROCEEDINGS.*

ANNUAL GENERAL MEETING.

THE ANNUAL GENERAL MEETING of the IRON AND STEEL INSTITUTE was held at the house of the Institution of Civil Engineers, Great George Street, London, on Wednesday, May 2—Mr. E. WINDSOR RICHARDS, M. INST. C.E., President, in the chair.

The Minutes of the previous meeting were read, confirmed, and signed by the President.

Mr. T. BARLOW-MASSICKS and Mr. H. J. BUTTER were nominated as Scrutineers by the President, and on the completion of their scrutiny they reported that the following gentlemen had been duly elected as members of the Institute:—

NAME.	ADDRESS.	PROPOSERS.
Anderson, John . . .	Cleveland Villa, South Bank, R.S.O., Yorks.	E. Windsor Richards, David Evans (Middlesbrough), Illtyd Williams.
Bellwood, George . . .	Cleveland Villa, South Bank, R.S.O., Yorks.	D. Evans (Middlesbrough), Illtyd Williams, J. E. Stead.
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Pollitt, Harry . . .	Gorton, near Manchester	Robert Colver, John D. Ellis, H. Herbert Andrew.
Rendell, Alan Wood .	Jamalpur, Bengal, India	Henry C. S. Dyer, W. S. Rendel, R. J. Billinton.
Rideal, Samuel, D.Sc.	28 Victoria Street, London, S.W.	W. C. Roberts-Austen, D. A. Sutherland, P. C. Gilchrist.
Rider, Henry Hyam .	Elm Tree House, Rotherham	John Hodgson, William Put- nam, J. G. Sheldon.
Ritchie, James . . .	Acklam Foundry, Middlesbrough	William Hawdon, William Hanson, R. Howson.
Roberts, Arthur Richard	Briton Ferry, Glam.	Edward P. Martin, William Evans, Enoch James.
Roberts, Robert . . .	Briton Ferry, Glam.	Edward P. Martin, William Evans, Enoch James.
Roberts, William Lionel	Fern Dale, Stourbridge	George Macpherson, Wm. Hutchinson, Wm. Roberts.
Rogers, John	Westbury Iron Works, Westbury, Wilts . .	Thomas Danks, Daniel Jones Hirst, William Evans.
Rogerson, Thomas Bond	Clyde Iron Works, by Tolcross, Glasgow	Andrew S. McClelland, James Riley, Iltyd Williams.
Sack, Hugo	Düsseldorf, Germany	George J. Snelus, R. M. Dae- len, Emil Schrödter.
Schmidt, Paul . . .	Kronprinzstrasse, Dort- mund, Germany	George J. Snelus, Hugo Haniel, R. M. Daelen.

NAME.	ADDRESS.	PROPOSERS.
Senior, Albert . . .	Pond's Forge, Sheffield	H. Herbert Andrew, George E. Hoyland, George Senior.
Sexton, Alexander	Anderson's College,	James Riley, George Ritchie,
Humboldt, F.I.C.	Glasgow	Walter Macfarlane.
Summerson, Robert	Haughton-le-Skerne,	David Dale, William Whit-
Bradley	Darlington	well, James I'Anson.
Summerson, Samuel	Albert Hill Foundry;	Sir Joseph W. Pease, John F.
James	Darlington	Wilson, Stephen Wrightson.
Thyssen, Fritz . . .	Mülheim on the Ruhr,	August Reichwald, W. G. Fos-
	Germany	sick, George L. Schultz.
Tolley, Richard Mentz	Darlaston, Staffordshire	Frederick Scarf, Harry Sil-
		vester, Henry A. Webb.
Tropenas, Alexandre .	5 Rue des Abondances,	Wm. Edgar Allen, G. Jackson
	Boulogne-sur-Seine,	Smith, R. Heber Radford.
	Paris	
Vaughan, William	London Works, Old-	Sir Benjamin Hingley, Ben-
Weaver	bury, near Birming-	jamin Round, W. Harley.
	ham	
Walrand, Charles . .	9 Rue Logebach, Paris	George J. Snelus, R. M. Dae-
		len, Emil Schrödter.
Wells, Alfred Ernest .	Imperial Steel Works,	Wm. Edgar Allen, G. Jackson
	Sheffield	Smith, R. Heber Radford.
Wigham, Frederick	25 Pinderfield Road,	George Craddock, J. E. Stead,
Henry	Wakefield	William Fry Whitwell.
Winterton, Albert	Park Gate Iron Works,	Sir James Ramsden, Sir Low-
While	Rotherham	thian Bell, J. M. While.
Woodward, Robert .	Imperial Steel Works,	William Whitwell, Wm. Han-
	Sheffield	son, R. Heber Radford.
Wotherspoon, John .	Etna Iron and Steel	John Spencer, George Garrett,
	Works, Motherwell,	Thomas Davie.
	N.B.	
Wright, Joseph Robert	North British Steel	Thos. W. Sorby, Joseph S.
	Works, Sheffield	Beckett, B. Geo. Wood.
Wylie, William . . .	Clifton Iron Works,	James Riley, George Beard,
	Coatbridge, N.B.	John Spencer.

The SECRETARY then read the following Report of the Council upon the proceedings of the Institute during the year 1893 :—

REPORT OF THE COUNCIL, 1893.

SINCE the Council submitted their last Annual Report to the members, the Iron and Steel Institute has completed the twenty-fifth year of its existence. Its career has been one of prosperity and usefulness, upon which the members may be congratulated.

THE ROLL OF THE INSTITUTE.

The Council have carefully scrutinised the qualifications of candidates for election, and have taken care that those recommended for ballot are either persons practically engaged in works where iron or steel is produced or worked, or persons of metallurgical attainments, or specially connected with the application of iron and steel.

During the year forty-nine names were added to the register, and seventy-two names are submitted to ballot at the present meeting.

During the past year baronetcies have been conferred upon Sir Frederick A. Abel (Past-President), Sir Benjamin Hingley (member of Council), and Sir Theodore Fry (member).

The following twenty-six deceases of members of the Institute have occurred during the past year :—

W. G. Ainslie.
Sir George Berkley, K.C.M.G.
Isaiah Bevan.
Edward Burkill Brooke.
J. L. Burns-Lindow.
Thomas Burrows.
Edward Carr.
James Colquhoun.
Edward Alfred Cowper.
Sir George Elliot, Bart.
William Evans (of Ferryside).
William Rowe Geen.
G. Kerr Hannay.

Thomas Hawksley, F.R.S.
John Head.
Robert Heath.
Charles James Homer.
John Jones (of Dowlais).
Alfred Longsdon.
Daniel Macnee.
The Baron Mayr von Melnhof.
Frederick Ransome.
Carl Richter.
Francis Rummens.
The Lord St. Oswald.
Joseph Schlink.

The following deceases, which occurred in 1892 and previous years, were brought to the knowledge of the Council :—

Washington Bagshawe.

Thomas Blake.

William Jenkins (of Dowlais).

Demetrius Jouraffsky.

Alberto Malo.

Ferdinand Pfeifer.

William Richardson.

Albert Edward Wilson.

There have been thirty-seven resignations of membership. The list of members has been carefully revised by the Council, and the names of several members whose addresses had been lost for some years, of gentlemen who, after having been elected, had not paid their entrance fee, and of those in serious arrear with their subscriptions were, in accordance with Rule 22, removed from the list.

SUBSCRIPTIONS.

The Honorary Treasurer having suggested that subscriptions should in future be sent direct to the Secretary and receipts issued by him, and that the duties of the Treasurer should be limited to those which more usually attach to that office, the Council has approved this suggestion, and members are requested in future to forward their subscriptions to the Secretary accordingly.

MEETINGS.

Two general meetings were held as usual during 1893. The spring meeting was held on May 24th and 25th at the Institution of Civil Engineers, whose constant courtesy in providing accommodation deserves grateful acknowledgment.

The autumn meeting was held at Darlington on September 26th and three following days. The titles of the papers contributed to the Institute's proceedings were as follows :—

1. On the Manufacture of Basic Steel at Witkowitz. By PAUL KUPELWIESER.
2. On the Waste of Fuel, Past, Present, and Future, in Smelting Ores of Iron. By Sir LOWTHIAN BELL, Bart., F.R.S. (*Past-President*).
3. On Iron and Steel at the Chicago World's Fair. By H. BAUERMAN, Assoc. M. Inst. C.E., F.G.S.
4. On Iron and Steel Wire, and the Development of its Manufacture. By J. P. BEDSON, Assoc. M. Inst. C.E.

5. On the Sampling of Iron Ore. By T. CLARKSON, Wh. Sc., Assoc. M. Inst. C.E.
6. On the Determination of Chromium in Ferro-Chromium. By W. GALBRAITH.
7. On Puddling Iron. By JOHN HEAD.
8. On the Tudhoe Works of the Weardale Iron and Coal Co. Ltd. By H. W. HOLLIS.
9. On the Lührig Coal Washing and Dry Separation Plant at the North Bitchburn Coal Co.'s Randolph Pit. By JAMES I'ANSON.
10. On Carbon in Iron. By Professor LEDEBUR (Freiberg).
11. On Suggested Improvements in Connection with the Manufacture of Steel Plates. By WILLIAM MUIRHEAD.
12. On the Recording Pyrometer. By Professor W. C. ROBERTS-AUSTEN, C.B., F.R.S.
13. A Supplementary Paper on a New Process for Desulphurising Iron and Steel. By E. H. SANITER.
14. On the Saniter Desulphurising Process. By G. S. SNEIUS, F.R.S.
15. On Methods of Determining Chromium. By J. E. STEAD.
16. On the Elimination of Sulphur from Iron. By J. E. STEAD.
17. On the Last Twenty Years in the Cleveland Mining District. By A. L. STEAVENSON.
18. On the Production of Wrought Iron in Small Blast-Furnaces in India. By T. TURNER, Assoc. R.S.M.

The autumn meeting, held at Darlington, a town not previously visited by the Institute, was very largely attended, and nothing was left undone by the Local Reception Committee that could add to the convenience and enjoyment of the members. To Mr. David Dale as chairman, and to Mr. James I'Anson as honorary secretary, the warmest thanks for these arrangements are due. The Council desire also to refer in grateful appreciation to the kindness and hospitality of the Rt. Hon. Lord Barnard, of Sir Theodore Fry, of the Worshipful the Mayor of Darlington, of the North-Eastern Railway Company, who liberally provided, without charge, special trains for excursions, and of the owners of important works who freely permitted members to visit their works. Visits to Consett Iron Works, the Tudhoe Works, the Evenwood Coal Washing Plant and the Lumpsey Iron Ore Mine were rendered all the more interesting by descriptions given of these works in papers contributed by Messrs. Jenkins, Hollis, I'Anson and Steavenson.

The Council are making arrangements to hold the autumn meeting in Belgium (on August 20th to 25th), in order to enable members to visit the Antwerp Exhibition. It is hoped that in 1895 it will be found convenient to hold the meeting at Birmingham.

PUBLICATIONS.

Of the Journal of the Institute, two volumes have been published during the past year; the two volumes together containing 1063 pages of letterpress and 45 plates. In addition to the papers read before the Institute and the discussion and correspondence relating to them, the volumes contain abstracts of the contents of 1130 papers relating to iron and steel published in other home and foreign technical Journals and Transactions. The second volume for the year also contains a description of the Consett Works prepared under the direction of Mr. Jenkins for the use of the members, and a report on the Chicago Exhibition from the pen of Mr. R. A. Hadfield, who kindly acted as representative of the Institute at the International Engineering and Metallurgical Congresses held in connection with that Exhibition. In the List of Members, which is a pamphlet covering 104 pages, several changes have been made. The authors of papers are indicated by distinguishing marks, and a topographical index of the members, showing the membership from every county and every town in the United Kingdom, has been added.

LIBRARY.

Additional bookshelf accommodation has been provided to meet the growth of the Library, which now exceeds 3000 volumes. Numerous presentations to the Library have been made, a list of which is given in the Journal of the Institute. For these the Council record their thanks to the several donors.

There are, however, numerous deficiencies of standard works on metallurgy and of volumes of Transactions, and it is hoped that members will volunteer to present these.

The additions to the collection of portraits include a marble bust of Krupp, a work of great artistic merit, bequeathed to the Institute by the late Mr. Alfred Longsdon, and a large photographic portrait of Sir Frederick Abel (Past-President), presented to the Institute by the Council.

THE BESSEMER MEDAL.

The Bessemer Medal for 1894 has been awarded to John Gjers, of Middlesbrough, one of the original members of the Institute, in recognition of his great services to the Iron and Steel Industries.

RETIRING MEMBERS OF COUNCIL.

The retiring members of Council are :—

Vice-Presidents.

William Evans. William Jenkins.
Sir James Ramsden.

Members of Council.

W. T. Crawshay. J. Cunninghame.
A Hewlett. Sir W. T. Lewis.
S. R. Platt.

Of these gentlemen, Mr. William Evans (Vice-President), Mr. W. T. Crawshay, Mr. A. Hewlett, and Mr. J. Cunninghame do not seek re-election, and the Council have nominated Mr. W. H. Bleckly (Warrington) as Vice-President, and Mr. Arthur Cooper (Middlesbrough), Mr. William Evans (Cyfarthfa), and Mr. Arthur Tannett Walker (Leeds) as Members of Council to fill the vacancies thus caused. For the vacancy on the Council caused by the promotion of Mr. Bleckly, they have nominated Mr. Victor Cavendish, M.P.

The Honorary Treasurer (Mr. DAVID DALE) read the Annual Statement of Accounts (p. 10).

THE IRON AND STEEL INSTITUTE.

STATEMENT OF ACCOUNT FOR THE YEAR ENDING DECEMBER 31, 1893.

RECEIPTS.		EXPENDITURE.	
To Entrance Fees	£04 10 0	By Balance due to Treasurer, December 31, 1892	£203 14 6
" Subscriptions	£019 16 0	" Salaries of Secretary and Clerks	950 0 0
" Journals sold	184 18 6	" Special payment to Retiring Secretary	333 4 5
" Interest	276 10 7	" Office Rent, Cleaning, &c.	72 8 7
" Bessemer Medal Fund Interest	10 10 11	" Purchases for Library, and Office Furniture	191 14 0
" Balance due to Treasurer	£3589 11 0	" Editing and Translating with Annual Meeting	19 18 4
	1588 9 5	" Expenses in connection with Annual Meeting	125 11 8
		" In London, May 1893	915 9 4
		" Darlington, September 1893	260 9 8
		" Journal Publishing Expenses	1 15 0
		" Printing, Advertising, and Stationery	16 2 4
		" Insurance	76 6 8
		" Bessemer Medal	52 14 4
		" Inland Revenue-Corporation Duty	
		" Postages, Receipts, &c., per Treasurer and Secretary	
		" Sundry Payments	
		" Special American Journal (Balance of Expenditure)	£3893 7 7
			66 7 7
			3899 15 2
			£5178 0 5

May 2, 1894.

(Signed) DAVID DALE, Hon. Treasurer.

INVESTED FUNDS OF THE INSTITUTE.

£1500 North-Eastern Darlington 5½ per cent. Stock, purchased at a cost of	£29398 7 0
£1681 North-Eastern 1876 4 per cent. Preference Stock, purchased at a cost of	1908 19 7
£680 North-Eastern Darlington 5 per cent. Stock, purchased at a cost of	1008 14 0
£1846* Scinde, Punjab, and Delhi 5 per cent. Stock, purchased at a cost of	1990 0 7
£760 Great Indian Peninsula Railway 5 per cent. Stock, purchased at a cost of	1287 6 0
	£3572 7 2

* This has since been compulsorily converted into an Annuity up till 1903, with a Sinking Fund to replace the amount of Stock, £1846.

The **PRESIDENT** said he hoped the members would consider the report of the Council and the statement of the Hon. Treasurer to be of a satisfactory character. It was now his duty to move the adoption of the report.

Mr. J. E. STEAD seconded the motion, which was unanimously adopted.

Mr. JEREMIAH HEAD moved, "That the most cordial thanks of the members of the Iron and Steel Institute be and are hereby tendered to the President, the Honorary Treasurer, and the Council for their services during the past year." It must be evident to every one that an institution of the character and magnitude of the Iron and Steel Institute could not be carried on without a very great deal of work, work which must be performed by an efficient permanent staff and superintended by able and assiduous members of the Council. Those gentlemen were certainly entitled to their very best thanks for their services; for the carrying on of the Institute gave to its ordinary members no trouble whatever—nothing in fact but pleasure and instruction. He therefore submitted that they should accord to their Officers and Council a very hearty vote of thanks for their kindness in managing all that important work for the benefit of the members.

Mr. J. W. SPENCER seconded the resolution, which was carried by acclamation.

The **PRESIDENT**, on behalf of the Council, wished to thank members for the expression of their approval of the work done during the past year, and also for their vote of thanks. Much time and careful consideration was given by the Council to all questions affecting the interests of the Institute, and the approval shown would encourage them to do all that they could for its continued prosperity. He hoped that in the vote of thanks it was intended to include the Secretary and his staff, who had worked in a manner very conducive to the interests of the Institute and very satisfactory to the Council. Their Secretary, **Mr. Bennett Brough**, was not like the proverbial new broom, which

did its work very well for a short time only. Four new members of Council had been elected—gentlemen eminently qualified to further the interests of the Institute. He thanked the members for their cordial vote of thanks to the Council.

THE BESSEMER GOLD MEDAL.

The PRESIDENT reminded the members that the Council had voted the Bessemer medal to Mr. John Gjers. Sir Henry Bessemer desired him to say that he would have been very pleased to have added a few words to those which he (the President) was about to use in presenting the medal to Mr. Gjers, but his doctor had prohibited him speaking. He was therefore very sorry that he would be unable to give expression to his approval of the action of the Council in presenting this medal to Mr. Gjers.

The PRESIDENT then handed the Bessemer gold medal to Mr. Gjers, and addressed him in the following words:—

Mr. Gjers, having had the pleasure of knowing you for very many years, it is a great satisfaction to me that the duty of presenting the Bessemer gold medal to you on behalf of the Institute has devolved upon me. As far back as 1865 you were actively engaged in designing and constructing the machinery and plant required in blast-furnace operations, and for several years you were the manager and adviser of several important works in Cleveland, West Yorkshire, Lincolnshire, and other parts of the country. In 1870 you concentrated all the experience you had thus obtained in the design and construction of your own Ayresome Works; a description of those Works you gave in a paper read before this Institute. Your invention of the Circular Calcining Kiln was a great improvement upon the older forms of kiln, and resulted in economy of fuel and better calcination of the ore. Your pneumatic hoist for lifting a railway waggon with its contents to the tops of the calcining kilns, and for lifting the materials to the tops of the blast-furnaces, was an ingenious and safe apparatus.

Your improvements in the construction of quick-running blast-engines made that type of engine successful, and it is now generally adopted in new installations in place of the slower running beam-engines. Your iron-pipe hot-air stove was a well-considered apparatus, and heated the blast up to 1000° F., which was considered at that time a high temperature. The Ayresome plant was, and is, a model plant, and probably, with the exception that you would adopt fire-brick stoves, there would not be any important change made if you were designing a blast-furnace installation to-day. In the Bessemer Steel Works of the Darlington Company, your active mind has suggested several improvements, and your name has become known all over the metallurgical world by your invention of the so-called Soaking Pits. I understand that over one million tons of ingots are now annually passed through these pits, and this represents a great saving in fuel, besides having other obvious advantages. All these matters were considered by the Council, and they unanimously decided that the work you had done during a long and honourable career, was deserving of the Bessemer gold medal. I have great pleasure, on behalf of the Institute, in asking your acceptance of this medal, and in expressing the wish of the whole of your fellow-members, in which I heartily join, that you may live long to enjoy the high honour now conferred upon you.

Mr. JOHN GJERS, in reply, said he was deeply sensible of the honour conferred upon him by awarding to him the Bessemer medal for the year. He could not but feel greatly flattered at the very kind and generous way in which the President had made the presentation. He would value the medal not only as a memento of the Iron and Steel Institute and of Sir Henry Bessemer, its founder, but would also look upon it as a kind of certificate that in the opinion of those able men who constituted the Council of the Institution, all of which were largely interested in iron and steel works, and were highly versed in everything connected with the iron and steel trade, he (Mr. Gjers) had been deemed worthy to receive the medal. He would also value it because he believed it was only the second occasion on which the medal had been awarded to a naturalised British sub-

ject. As many of the members were no doubt aware, he was not a native of this country. He was born in Sweden, and in his veins flowed that pure Scandinavian blood which was so largely intermixed with their own. He would remind them that some centuries ago, and during a succession of centuries, there was a very large influx of Scandinavians into England, led by their Sea Kings and Vikings. They took possession of the whole of that part of Britain which previously was occupied by the Romans; they even gave the name of England to this country, and from that blood was derived many of those qualities of which Englishmen were so justly proud. Active, intelligent and persevering; lovers of liberty, though law-abiding; great respecters of women; honourable and enterprising: such were the qualities which characterised the Vikings of old, and such were the qualities which characterise Englishmen to-day. He had spent the whole of his active and useful life in this country; all his worldly interests were here, and all that a man valued in family ties and friendships were centred in England. He was bound to say that he admired and loved this, his adopted country, better than any other country in the world. As a very young man he came to England to see the great exhibition of 1851. In 1854 he came to Middlesbrough, and in 1855 he was appointed by the late Mr. A. B. Cochrane to be manager at the newly built Ormesby Furnaces, as successor to his friend the late Mr. Edwin Jones. It was fortunate for him that the eldest son, Mr. Charles Cochrane, whom they all knew so well, became the resident owner, and that he (Mr. Gjers) became his right-hand man; for although only of about the same age, still his energy and pluck, his independence of thought and action, and his great desire to get out of the old ruts and to improve upon the management of blast-furnaces, was a new light to him, opening his eyes to possibilities which he had since seen more than realised. He was glad to say that he owed much of his success in life to the good example he received from his early employer and friend, Mr. Charles Cochrane. About that time (1855) were commenced those great improvements in blast-furnace practice, the development of which continued for about fifteen years, in which Cleveland continually took the lead, which caused a complete revolution in the practice and work of blast-

furnaces—he referred to the complete utilisation of the blast-furnace gases for heating purposes, which was the first. The second improvement was the great increase in the heat of the blast, which, as they were aware, was increased from about 600° to 1200° and more. A third improvement was the largely increased size of furnace, which was gradually increased from about 5000 cubic feet to about 25,000 cubic feet and more; all these improvements caused a great revolution in the blast-furnace trade and great economies resulted, and the example of Cleveland was followed more or less throughout the whole of the iron districts of the world. In 1870 he was appointed the responsible blast-furnace manager to some new furnaces built by Messrs. Snowdon & Hopkins of Middlesbrough. From that time he was glad to say he never looked behind, but was fortunate in finding employers in Mr. William Hopkins, Mr. Isaac Wilson, Mr. Edgar Gilkes, and the late Mr. Lloyd, who had confidence in his practical ability and judgment; and in succession he designed and built for these owners the Linthorpe Ironworks in 1864, and the Teeside Furnaces in 1866. About that time, as the President had been good enough to mention, he was also engaged in various other works in different parts of the country, so that he had his share in carrying out those improvements that had taken place, and had even invented a number of practical details himself; and he eventually became senior partner in his present firm of Gjers, Mills, & Co., and designed and built the Ayresome Ironworks in 1870. They would notice that nearly all his life had been spent about blast-furnaces. The President was good enough to mention his connection with the steel trade—it was nothing very extensive, but he had done a little; and he also mentioned the soaking pits. Of course the soaking pits were now so well known that he need not say anything further about them. It was quite right, as the President mentioned, that over a million tons were passed through the soaking pits last year and paid a royalty, but he might say that at least as much more had during that year been passed through soaking pits in a modified form where the royalty had been refused; so that altogether he had shared the fate that, more or less, fell upon inventors of introducing things of which they did not reap the entire benefit, but certainly the invention had become

of great practical value. He would say nothing further except again to thank the members and the Council for the honour they had conferred upon him in presenting him with this medal, which he would always value greatly.

Mr. E. WINDSOR RICHARDS then delivered the following Presidential Address:—

PRESIDENTIAL ADDRESS.

THE practice of your President delivering more than an inaugural address became established by Dr. Percy, and has been followed ever since by all succeeding Presidents. Custom decides that ordinarily the address shall be a comparatively short one.

In 1886 the learned Doctor referred to the then universal depression in the iron and steel industries, and to over-production, adding that either consumption must be increased or production limited. All interested in these industries have said the same thing many times over.

Our own country is too small to keep our immense establishments occupied; we have lost the greater part of the Continental trade owing to protective tariffs, having for their main objects the fostering of their own industries and finding occupation for their own population. We anxiously look abroad for fresh fields to receive our products, so as to maintain, and possibly increase, consumption.

Always keeping in mind the fact that our Institution confines its attention almost wholly to iron and steel, my remarks refer only to those industries.

I must be careful not to transgress Rule 2, which states that the object of the Institution shall be to afford means of communication between the members of the iron and steel trades upon matters bearing upon their respective manufactures, excluding all questions connected with wages and trade regulations.

Since that rule was framed, the Institute has become quite cosmopolitan in character.

During the whole of last year the depression was so great that there was little encouragement to spend money to improve either processes or machinery, so that there is little in this direction to call your attention to. Indeed, there is a lull in invention, with few new developments, and there seems to be almost as little new to record in steel-making as there is anything fresh to say about the puddling process.

1894.—i.

B

Under these circumstances, therefore, I purpose deviating a little from the beaten track in this short address; my excuse being that it is impossible for those engaged in metallurgical pursuits to separate the consideration of the commercial from the manufacturing aspect of our industries, so intimately are both associated and bound together.

During the two years of the learned Doctor's presidency, which he characterised as "those of great depression," the production of Bessemer steel rails in 1885 (as given in the "British Iron Trade Journal") was 706,583 tons, and in 1886 it increased to 730,343 tons; whereas in 1893 the same source shows that the depression had become more accentuated, for we find the figures are lowered to 579,386 tons, which was less than for many years except the previous year, when the production was 43,550 tons lower than in 1893. The price of rails, which in 1886 was £4, 13s. 10d. per ton in England, fell to as low, in some instances, as £3, 12s. in 1893. These figures show that the production of iron and steel has become very greatly restricted, and the question the country generally is deeply interested in is, whether the diminished demand is due to any falling off in quality of material, excellence of finished products, or increased cost of manufacture? I feel quite sure, from careful observations made at several establishments, that our metallurgists and manufacturers still keep a foremost position, and have not fallen away in any one of the above respects. It is true we have almost lost our Continental trade, but it is not for the want of skill or knowledge of manufacture, but by reason of protective tariffs which operate against us in two ways: first, the high tariff rate we are called upon to pay for admission to the various countries, to a great extent excludes our products; and secondly, the high prices obtained by our competitors enable them to make such substantial profits in their own country that they can afford to quote very low prices, leaving them little or no profit when in competition with us. This may seem paradoxical, but the object is to obtain as large a production as possible, as that has proved to be of very great importance in reducing general and establishment charges.

But even under such greatly disadvantageous conditions, we have several times quoted and obtained considerable orders for

rails, delivered inland on the Continent, at prices which have left a profit. The competition has, however, become altogether one-sided, for the railway companies have latterly, after receiving the lowest tenders from us, allowed their manufacturers to amend their offers, so that we are quite shut out from those countries, whilst our own is left open to their attacks. I could cite many instances of this what I term unfair competition; the figures have many times been published in the newspapers, and so are public property. The following recent example illustrates what I particularly desire to direct attention to. In January of this year, England tendered for some steel rails delivered in Oldenburg at a price of 109 marks per 1000 kilos; the lowest German tender was 114 marks. Notwithstanding a strong protest, the order was given to the German firm at the English price, but if the German manufacturers had been tendering for steel rails for delivery in England, their price would have been about £3, 15s. per ton or less. In the English tender before referred to an import duty of £1, 5s. 6d. per ton was included, as well as the cost of carriage; so I repeat that, though it is generally thought otherwise, the successful competition is not accomplished by greater skill or by more economical methods of manufacture.

We have been repeatedly advised to adopt better methods of working, to construct further labour-saving contrivances, to afford a better and more thorough technical education. We have continually advanced in these matters. We are still doing all that lies in our power in those directions, and much yet remains to be done. But of what avail is it to construct labour-saving machinery, and so throw more men out of employment, when we have already thousands of willing hands out of work? And then labour-saving machinery can be, and is, as readily and as quickly adopted by our competitors as by us. Thorough technical education is of the very utmost importance, and is receiving the greatest attention from the highest and best people in our land. But what even will technical education avail us against the unfair conditions I have pointed out? And what relief will these things, which are so generally and so persistently preached to us, give us when they are adopted? They can give no relief in the present condition of things.

Never since the organisation of this Institute has the metallurgist experienced a more difficult time than the depression we are passing through. Added to his commercial troubles are constant demands from the workmen for either higher wages or fewer hours of work. The gravity of the situation demands the closest consideration of commercial men and of statesmen. We may well anxiously look round to see where the markets for our produce and employment for our workmen and capital are to come from.

Great hopes are entertained at home that the tariff laws in America will be so altered and improved in our favour that we shall be able to resume delivery of iron and steel to that country. But American legislators are perfectly well aware of the needs of their own country, and know quite well that their own industries must first be fostered, and employment found for their own people. We may rest perfectly assured that they will legislate in that direction, and not in favour of England or any other country to the detriment of their own. We should not turn our eyes either so much to America for a market, for they have experienced a far greater degree of depression than we have. Nor must we look to Continental nations to take our iron and steel, for they are well able to supply themselves; and if present tariffs are not sufficient to keep out our productions, they will be increased. We cannot and do not complain of countries fostering their own industries, but we claim to exercise our privilege of grumbling when these tariffs are so high as to enable our competitors to poach on our lands and throw our workmen out of employment, and especially when, by placing even a small quantity of iron and steel in Great Britain, they depress the value of the whole of our products, and we have reason for complaining of a competition which is so one-sided and unfair to our manufacturers.

But we must look to our own possessions and to our own Colonies for relief, and our legislators must safeguard their interests and ours. Canada is thoroughly loyal to us, and needs our markets as much as we need her to take our surplus population. We look anxiously for further development of railways in India and Australia, and Africa should, ere long, become of enormous advantage to us.

It is to be hoped that our legislators may find time to consider these important questions, which affect the well-being of so many thousands engaged in the iron and steel industries, and are indeed of vital interest to the whole of the community.

The invention of our venerated and most highly esteemed Past President, Sir Henry Bessemer, conferred the greatest good on the greatest number, but even he could scarcely have imagined that steel rails would be put on board ship at £3, 12s. 6d. per ton. The manufacturer, not being included in the category of the greatest number, would perhaps not complain so much of the price if he could obtain enough employment to keep his workmen together until times improved. One cannot wonder, however, that orders for rails are few when we are informed that those laid down from Ostend to Brussels, made to Mr. Sandberg's Goliath section of flange rail weighing 105 lbs. a yard, have recently been accurately gauged after being in use for five years, and are calculated, at present rate of wear, to last a hundred years. These rails were made at Seraing, and contain from 0·4 to 0·45 of carbon.

We learn that rails are being laid down abroad containing as much as from 0·6 to 0·7 carbon, the object being to lengthen the life of light sections of rails. One can only regard such extremes with alarm, and there can be no necessity for running such great risks to life and property when heavy rails are so cheap and last so long. We hope and believe that such a dangerous practice as this will not be imitated in Europe.

Very considerable trouble and expense have been experienced by manufacturers through differences in analyses by different chemists, and it seems to be a desirable thing that a committee of our chemical members should be appointed to consider whether standard methods of analysis could be determined on, and if so, that such standards should be recognised and adopted in the trade for our guidance.

For such a purpose as this, and for scientific research generally, in which our members are interested, we might well make grants of money from the funds of the Institute.

It is the intention of the Council to consider this matter, and they will ask your consent that such grants may, from time to time, be made in aid of scientific research.

Dr. Dudley of Altoona has just sent me a description of an attempt made to ascertain the quantity of phosphorus in three samples of steel. A large quantity of drillings was taken from each of the three samples, care being taken to eliminate the influence of segregation as much as possible; he analysed some himself and sent the others to several eminent chemists. The results varied.

In No. 1 sample from 0.035 to 0.042.

In No. 2 sample from 0.041 to 0.056.

In No. 3 sample from 0.019 to 0.033.

And at home we find quite as much difference as these analyses show, and much vexation and loss have been occasioned thereby.

Permit me to call the attention of steel-makers to the unsatisfactory manner in which ingots are generally made. It is a rare thing to see clean, well-made, sound ingots. What with running stoppers, sand marks, cracked moulds, and stickers, the present method of ingot-making is not creditable, and should be improved.

I own to having been as great a sinner in this respect as it is possible to find, but I made many efforts to extricate myself from the position, but without much success. It was owing to my failure to improve ingot-making that induced me to reduce the number of ingots made per cast by doubling the size of the ingot, and so having only one half the number to make; and to deal with the greatly increased size, I designed and made the cogging-rolls 39 inches diameter, and so dealt effectually and economically with ingots 16 inches square, rolling them into rails over 150 feet in length.

After successfully dealing with ingots for rails weighing up to about 30 cwts., and being still extremely dissatisfied with the ingot-making department, I much desired to go further and reduce again the number of ingots made per cast.

About this time we constructed at Eston rolls 5 feet diameter to reduce ingots weighing 5 tons to slabs 30 inches by 6 inches thick for plate-making; this was then found to be, and is to-day, a most successful and economical plant. I was thus not far from the task I had set myself of dealing with one ingot to one cast, but was deterred from going further at that time by two considerations—1st, A dim fear of segregation, and, 2nd, a strong fear of the great length and weight of the rolls of so large a

diameter as 5 feet. If the hydraulic forging press of a couple of thousand tons power had been available in those days, I believe that at Eston we should long ago have been making a cast of from 8 to 10 tons of steel into one ingot.

This seems a small thing to say at this time, when ingots 6 feet 9 inches square, weighing up to 70 tons, are being dealt with by the hydraulic forging press, and easily handled by appliances which have been so simplified and perfected that weights up to 100 tons can be manipulated with perfect ease and safety.

Messrs. John Brown & Co., of Sheffield, are having constructed a forging press which will exert a force of ten thousand tons.

At this time, when our steel rail makers have only limited employment, and also when it happens that we have at the head of affairs many young men, the occasion offers for the exercise of skill and invention in the direction I have indicated.

The general depression in trade is still with us, and the hope of better things is long deferred.

Over the whole civilised world men's minds are much agitated and discontented, and many are the serious and difficult problems to be solved.

However unreasonable and drastic are the changes now proposed and demanded, we have faith in the sound common sense of our countrymen, but I desire to emphasise an expression of hope that they will first most carefully consider where the proposed changes are likely to lead us to, remembering we are only a small number compared with those who are competing for the trade of the world, and if we make serious mistakes we shall be compelled to retrace our steps after undergoing much needless suffering, and shall probably find, when too late, that some of our trade has been permanently lost to us.

VOTE OF THANKS.

Sir LOWTHIAN BELL, Bart., remarked that every official act performed by their President would, he had little doubt, satisfy members, as they had already satisfied him, that the Council made a wise selection in suggesting Mr. Windsor Richards as President of this now most important Institution. It might be that some of their members might think that the President had trod, very nearly, if not quite, upon some forbidden ground for their discussions; but they must remember, in justification of the step that had been taken, that they were living in times of exceptional severity. He said this because he was compelled to listen from time to time to persons in very exalted positions, who appeared to think that they understood the business of members of the Institute very much better than they understood it themselves. The part of the President's speech to which he would take particular exception, if he might be allowed to be so bold, would be with regard to relying, after recent experience, too much upon the wisdom of statesmen for guidance in the conduct of their business, either in the iron trade or in its allied occupations. However, he was not going, as might be imagined, to criticise at any length the action of those high in the social scale. His duty was simply to move, "That the best thanks of the members of the Iron and Steel Institute be and are hereby presented to the President for his admirable address, with the request that he will allow it to be printed." This motion he begged leave to place before them.

Mr. ANDREW CARNEGIE said it was his pleasant duty to second the motion just proposed by Sir Lowthian Bell. Sir Lowthian had stated the feeling with which their election of the President was regarded on this side of the Atlantic. He (Mr. Carnegie) could also assure the members that the cordiality with which it was received on the other side of the Atlantic was equal to that which hailed the election here. In America they regarded Mr. Richards not as a foreigner. He had already paid two visits to the United States, and he hoped that he would pay many more. One

reason why the President treated the commerical question in such a broad and able manner was no doubt because he had knowledge of what had taken place and was taking place with the American manufacturers, and if misery loved company, he had a very loving message for all of the steel and iron people in this country. The depression in America was greater than their own; the circumstances surrounding it were precisely similar to those described by Mr. Richards, except in regard to the foreign trade; and just as he had implicit confidence in the complete restoration of the Republic to its wonted prosperity, so did he abate no jot of hope that Britain under equal conditions, which were bound to return, would once again prove that she occupied the position which she occupied in the past. With regard to the present, he should say that they had not lost their position relatively to other countries. He had great pleasure in seconding the motion.

The motion was carried by acclamation.

The PRESIDENT expressed his sincere thanks to the members for the hearty manner in which they had responded to the resolution.

The following paper was then read:—

THE WALRAND-LEGÉNISEL PROCESS AS APPLIED
TO STEEL CASTINGS.

BY GEORGE J. SNELUS, F.R.S., VICE-PRESIDENT.

BELIEVING that the members of the Institute desire to be informed of every new departure in steel-making, and having had, through the kindness of Mr. Daelen of Düsseldorf, the opportunity of witnessing the Walrand process at Hagen in Westphalia, and subsequently of seeing it carried out by the inventors themselves at their own works in Paris, the author has endeavoured to lay before the members as complete an account of the process as the circumstances and time at his disposal admitted. In this he has been much aided by the prior investigation of Mr. Daelen, the agent for Mr. Walrand in England and Germany, who has already supplied a short paper on the subject to the *Stahl und Eisen* (No. 19, 1893), and by the very careful and elaborate investigation of the process from a mechanical point of view by one of the junior members of the Institute, Mr. Ernest F. Lange of Messrs. Beyer & Peacock's Locomotive Works, Gorton Foundry, Manchester. The samples for analysis were taken by the author, and carefully analysed in duplicate in his laboratory by Mr. Geo. J. Snelus, jun., and his assistant, Mr. Robert Lowe.

Mr. Daelen, in his article in *Stahl und Eisen*, calls attention to the well-known fact that converters of less than five tons capacity have not been generally successful, owing to the small charge of metal chilling so rapidly, and that the same holds good with the Siemens furnace. He also points out that the tendency has been to gradually increase the size of converters and open-hearth furnaces, thereby reducing the cost of ingots, but making the output so heavy that it becomes totally unsuitable for ordinary foundry work, and that with the smallest furnaces in steel foundries, the output is so great, that part of the product has to be turned into ingots, which have to be sold in competition with the cheaper ingots from the larger furnaces, because the Siemens furnace must be kept going.

Many attempts have been made to get over the difficulty of want of fluidity in small converter charges, but as far as the author knows there has hitherto been little success in this direction. Mr. Legénisel began his experiments in 1884 with a small converter of 5 cwt., erected at his foundry in Paris. Being a large producer of malleable castings he sought to extend his operation by adding steel castings, but he met with no success, owing to the difficulty of keeping the metal fluid. Mr. Walrand joined Mr. Legénisel in 1891, and after many experiments which were practical failures, the idea suggested itself of blowing the metal in the ordinary way till the flame dropped, then turning down, and after adding a quantity of fluid ferro-silicon, blowing again for a short period, producing, as in the basic process, an *afterblow*, during which a large amount of heat is generated by the rapid combustion of the added silicon, with the further advantage, that as the silicon burns to a solid the metal is left free from gas, and what gas it did contain is more easily eliminated by the greater fluidity of the metal. This idea of getting more fluid metal by an afterblow in which the substance burnt should produce a solid, so as to reduce the occluded gases in the bath, was entertained by the writer some ten years ago, and a large number of blows were made at the West Cumberland Works by turning down the vessel at the drop of the flame, then adding spiegeleisen and blowing again for some two minutes, to burn out the added manganese. The metal was found to be undoubtedly more fluid and freer from gas cavities than ordinary metal, but the difference was not so great as to warrant continuing the process. Ferro-silicon did not commend itself to the author at the time, as he was making rail steel, and had always a dread of excess of silicon with high carbon. From the analytical results given below it appears that this was a groundless cause of alarm, as there appears to be no difficulty in practically eliminating the added silicon by the afterblow. Silicon has two distinct advantages over manganese for this purpose; 1st, it generates a much greater quantity of heat unit for unit; 2nd, the time to terminate the afterblow is better marked by the flame indication when silicon is used. The chief difficulties met with by the author in his experiments was this want of indication when to discontinue the afterblow, and

he tried, 1st, to judge by the flame; 2nd, by the spectroscope; 3rd, by adding always a definite proportion of manganese and passing the same volume of air through the vessel, judging the quantity, 1st, by the time of blowing; and 2nd, by the number of strokes of the blowing engine.

It will probably be asked, why not begin by using a more siliceous pig iron to start with, or by adding the ferro-silicon during the ordinary blowing? These plans have been tried, and have not proved satisfactory, because in either case the heat generated by the combustion of the extra silicon is largely carried out of the converter by the great volume of gas going off, and second, because when an excess of silicon is used in this way, it is difficult to get rid of it entirely before the carbon is all burnt.

The Walrand process then consists in simply adding to the metal at the end of the ordinary blow a definite quantity of melted ferro-silicon, then making the afterblow, turning down when the extra silicon has been burnt out, and adding the ordinary final additions of ferro-manganese, &c., as circumstances require. The advantage is, 1st, that you can use an ordinary Bessemer pig iron with 2-3 per cent. silicon, thus ensuring a steel comparatively free of silicon; 2nd, that the combustion of the added silicon produces such a large amount of heat *at the right time*, and so *rapidly* that the metal becomes very fluid; 3rd, that as the silicon burns to a solid, it leaves the metal comparatively free of gas, and the steel is sound and free from gas cavities; 4th, that in consequence of the metal being so fluid and already free from oxide of iron, the ferro-manganese or other substances added, such as aluminium, are more effective and remain in the final steel; 5th, that in consequence of the great fluidity of the metal, much more time and facility is given for casting operations.

In describing the experiments witnessed by the author, it may be best first to describe those carried out at Paris by Messrs. Walrand & Legénisel. It should be stated, however, that the author was first invited by Mr. Daelen, at the Darlington meeting, to witness the process at Hagen, where a new installation had recently been put up, and where some remarkable results had been obtained. At the same time Mr. Lange was invited to Hagen, and made his first visit on November 28, 1893. He was so

satisfied with the results obtained that he arranged to make a second visit with the author on December 5, 1893. At the last moment the author was prevented from attending, and Mr. Lange went alone, meeting there, however, a number of German engineers. On January 19, 1894, the author and Mr. Lange met at Hagen and saw three blows, and took samples, the results being recorded below. The satisfactory character of these results being mentioned to Mr. Croasdell of the Lowca Engineering Co., Whitehaven, who had been anxiously looking about for a method of producing steel castings suited to a general foundry, interested him so much that he requested the writer to join him in a visit to Paris to see the process carried out by the inventors themselves. This visit was made on the 5th and 6th April. The first day was spent in examining the plant and getting general information. On Saturday, the 6th, they started to blow at 2.30 P.M., and made four complete charges, from the last of which samples were taken for analysis, with the results recorded below, while mechanical tests of the former were made between the casting operations.

At Paris they have two small converters, one for 300 kilogramme charges and one for 600 kilogrammes. Both vessels are turned down by hand power. The blast is taken from the city pressure service, being passed through a reducing valve to reduce the pressure from five atmospheres to one to two atmospheres. A drawing of the smaller vessel is given herewith (Plate I). On the present occasion the smaller vessel was used. A mixture of English pig iron, chiefly Ayresome and Harrington, is employed, as, after many brands had been tested, these were found most suitable. The cost at present is about 90 francs per ton (2000 lbs.). Coke costs 32 francs per ton, and the selling price of steel castings is about 24 shillings per cwt. The pig iron is melted in a small cupola, and brought in a ladle by an overhead crane to the vessel. The ferro-silicon is melted in a very small cupola of ingenious construction, the blast being heated, the melted metal dropping into a heated crucible as it melts, and being weighed before use (Plate II.). There are usually six small tuyeres in the small vessel, eight in the large vessel. These are made at Le Creusot, but the quality of the fireclay is not equal to English. They last seven to eight blows in the small vessel, ten to twelve

in the large vessel. One thousand charges from the same lining have been run in the large converter.

Mr. Walrand finds a loss of 5 per cent. on the iron melted in the cupola, 10 to 12 per cent. loss of metal in the converter. About $\frac{1}{2}$ per cent. silicon is lost in melting the ferro-silicon. The ferro-manganese added is melted in a crucible, and the aluminium is put in in small pieces during pouring and casting.

The following tables give details of the four blows:—

I.

Time.		Weight.
Minutes.	Charge—	Kilogram.
	Ayresome No. 1	250
	Harrington No. 1	55
22 { 13	1st Period—	
	Blast pressure, 1.62 atms.	
9	2nd Period—	
	Addition of ferro-silicon	20
2½	3rd Period or "afterblow"—	
	Average blast pressure, 1 atm.	
	Addition of ferro-manganese	12
	Blow about 15 seconds to mix ferro-manganese.	
	500 grammes Al. added per 1000 kilos. of charge.	
	Total charge	337

II.

Time.		Weight.
Minutes.	Charge—	Kilogram.
	Ayresome No. 1	250
	Harrington No. 1	55
	Blow commenced at 3.38 P.M.	
	Pressure of blast variable commencing at 2 atms.—	
	At 4 minutes 1.9 atms.	
	At 9 " 2.25 " beyond capacity of gauge.	
	At 13 " 0.8 "	
	At 15 " 0.9 "	
	At 18 " 1.0 "	
24 { 13	1st Period.	
11	2nd Period—	
	Addition of ferro-silicon	15
1:33	3rd Period or "afterblow"—	
	Addition of ferro-manganese	12
	4th Period—	
	8 seconds to mix ferro-manganese	
	500 grammes Al. added per 1000 kilos. of charge.	
	Casting completed at 4.17 P.M.	
	Total	332

III.

Time.		Weight.
Minutes.	Charge—	Kilogrm.
Sample spanners from his cast.	Ayresome No. 1	250
	Harrington No. 1	55
	Commenced blowing 4.33 P.M.	
	Blast pressure 1.5 atms.—	
	At 7 minutes 1.8 atms.	
	At 12 „ 2.0 „	
	At 19 „ 1.0 „	
	1st Period—	
	D line full, 4.46-5 P.M.	
	Mr. Legénis's Note, 1st Period, 12.5 minutes.	
	4.48-5 P.M. D lines coming into view.	
	4.50 „ D lines permanent.	
	4.51 „ green lines just starting.	
	2nd Period—	
	Addition of ferro-silicon	15
	3rd Period or "afterblow"—	
	No green line, visible 4.58½ to five o'clock.	
	Addition of ferro-manganese	12
	4th Period—	
	At 5 hours 1½ minutes vessel turned up to mix ferro-manganese.	
	500 grammes Al. added per 1000 kilos. of charge.	
	<i>Casting finished 5.10 P.M.</i>	
Total		332

IV.

Time.		Weight.
Hours.	Minutes.	Kilogrm.
21½		Charge—
		Ayresome No 1
		Harrington No. 1
		Sample I.—Melted pig.
		Blow commenced.
		D line appearing.
		„ permanent.
		Mr. Legénis's Note, 1st Period, 11 minutes.
		Potassium line appearing
		Green lines fitting.
		„ „ permanent.
		Flame full. Blast 0.9 atms.
		Turned down. See spectrum.
		Sample taken No. II. Blown metal.
		Addition of ferro-silicon
		Afterblow commenced. Time, including turning up,
		1 minute 18 seconds.
		Sample taken No. III. End of "afterblow."
		Addition of ferro-manganese, vessel turned up to mix
		Two samples of cast taken (No. IV.), one without
		carbon in ladle and one with No. V.
		500 grammes of Al. added per 1000 kilos. of charge.
		Metal in ladle very fluid. No skull.
		Finished casting.
		Sample VI.—Melted ferro-silicon.
Total		332

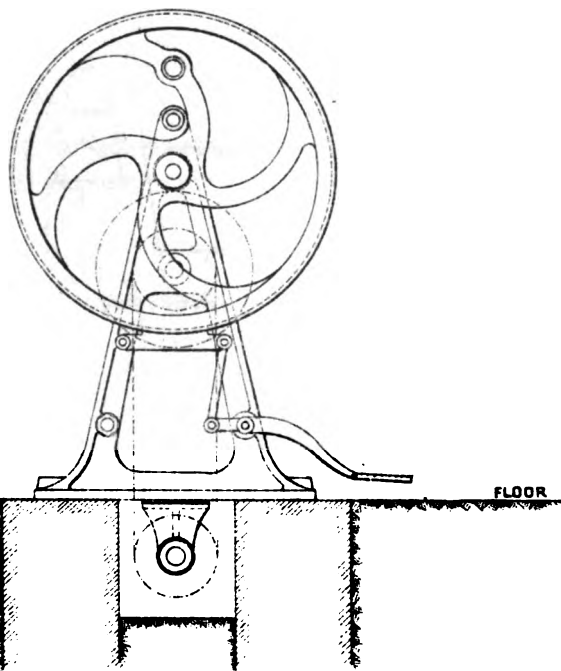
The following table gives the results of analysis of the samples from No. 4 blow :—

	I.	II.	III.	IV.	V.	VI.
	Melted Pig Iron.	Blown Metal.	Metal after Afterblow.	Finished Steel with out Carbon in Ladle.	Finished Steel with Carbon in Ladle.	Ferro- silicon (melted).
Iron (by difference) . .	92.72	99.801	...	...	...	80.795
Combined carbon . .	trace	0.13	0.12	0.25	0.255	trace
Graphite	3.45	...	...	...	...	4.543
Silicon	2.93	0.018	0.013	0.043	0.042	10.419
Sulphur	0.037	0.033	0.039	0.035	...	0.065
Phosphorus	0.043	0.043	0.055	0.069	...	0.115
Manganese	0.820	traces	traces	0.288	...	4.063
Aluminium . . . .	...	...	...	...	...	...

Plate III. shows the spectrum of the flame at its brightest, about two minutes before turning down. At the moment of turning down some of the green lines had disappeared, but those nearest the D line were still visible, indicating that Mr. Walrand turns down early. The second drawing shows the spectrum at this point. After the ferro-silicon has been added, and the vessel turned up again, the green lines are scarcely visible (see drawing). The appearance of the flame to the naked eye seems to be the best guide for finishing the blow. The flame of this afterblow gave almost a clear spectrum, only the sodium and potassium lines being clearly visible, a few green lines occasionally visible (see spectrum). It will be seen from the tabulated statement that 250 kilogrammes Ayresome and 55 kilogrammes of Harrington pig iron was used. After blowing $22\frac{1}{2}$ minutes the vessel was turned down, and 15 kilogrammes ferro-silicon added. Practically the whole of the silicon and carbon and manganese in this was burnt out in 1 minute 18 seconds. Then 12 kilogrammes ferro-manganese containing 30 per cent. manganese was added, and to the ladles of metal as drawn from the vessel aluminium was added at a rate of 500 grammes per 1000 kilogrammes. Sometimes an extra allowance was added. The metal was drawn from the converter into ordinary foundry ladles at three or four operations, and it will be noted that the last casting was made nearly 20 minutes after the blow was finished, the steel being perfectly

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SIDE ELEVATION
OF ROTARY MOVEMENT.



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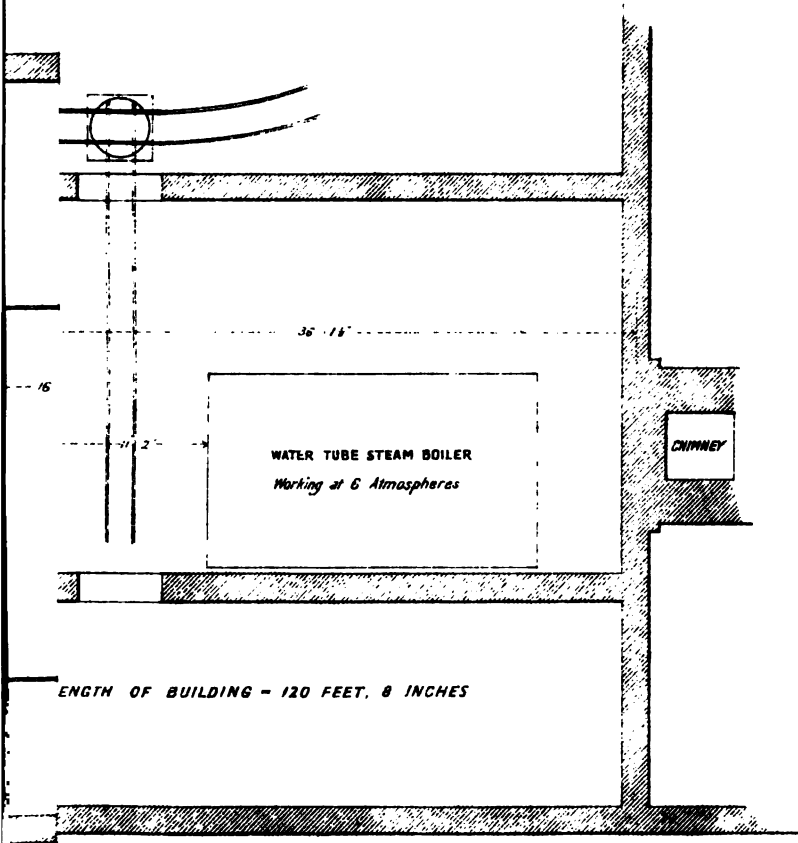


Fig. A.

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Fig.

PLATE III.

Fig. A

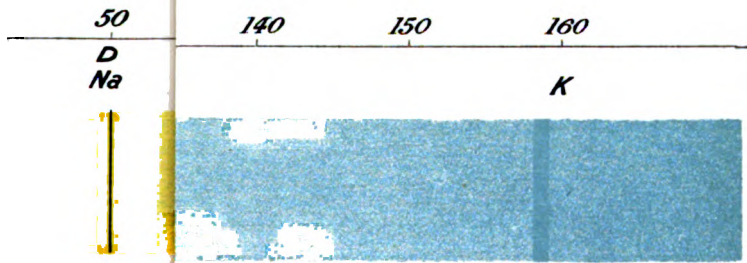
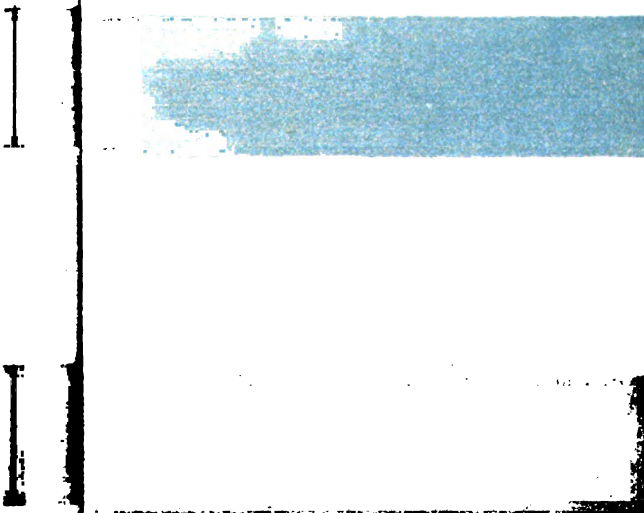


Fig. B



fluid then, there being no ladle skull. The steel ran quietly into the moulds, with not the least sign of boiling, sparking, or evolution of gas, the contraction apparently being just that due to change from fluid to solid state. It will be noticed that the steel is of quite soft quality, and does not contain an excess of silicon. Samples of the castings are laid on the table, the delicate runners into the air-holes indicating the fluid character of the steel, the turned and fractured surfaces showing its soundness.

HAVING finished our investigation at the Paris works, and learning from Mr. Walrand that Messrs. Schneider had also an installation at Le Creusot, we made a rapid visit to the works, on the chance of what we might see. We were most handsomely received by Mr. H. Schneider, and shown through the works by the manager, Mr. Bouvard. We found the Walrand installation a counterpart to the one at Hagen, and we were shown a number of the steel castings, chiefly tram wheels, cast in *green sand*, which were excellent, but unfortunately they were re-lining the converter, and we could not see a blow. We were informed that the process was very satisfactory.

It may interest the older members of the Institute to know that revolving puddling is in successful use at Le Creusot. The Danks furnace has been so far improved by Mr. Bouvard, the able manager there, that several of them have been working continuously for some years with great success, the puddled iron being used in Siemens melting furnaces for their best steel. The rotators are water-cased entirely, but on a different system to Crampton's. Coal fires are used with blast under the grate.

To return to the description of the process as carried out at Hagen. This installation, being the newest, is undoubtedly the most complete. We were shown every courtesy by the managing director, Mr. O. Müller, and the manager, Mr. J. Kracht, and all questions were fully answered. Appended is a drawing showing the arrangement of the plant (Plate II.).

The following description of the works is by Mr. Lange:—"The plant consists of two small converters of 600 kilogrammes (12 cwt.) capacity each. It is, however, possible to deal with 750 kilogrammes (15 cwt.). The space across the shop is arranged for two small cupolas, of which one is at present erected, along with

a windlass and hoist; the windlass being worked by a rope from the engine working the Roots blower in the engine-room adjoining. In this engine-room is the blowing engine for the converters. When the work of the foundry necessitates the utilisation of both converters at once, the engine will be completed to a compound vertical. At present, only one converter being used, the high-pressure portion of the engine is alone finished. Adjoining the engine-room is the boiler-room, containing a water-tube boiler working at six atmospheres. An overhead travelling crane, worked by hand, traverses the shop. The casting-shop is 68 feet in length, 43 feet wide. The engine-room is 24 feet by 22 feet, and the boiler-house, 35 feet 6 inches by 22 feet. The converters are both of the shape shown in Plate I. The converters and bottoms are rammed in the usual way. The cupola is of the Luhrman-Greiner type,* which is meeting with considerable success in Germany. The blowing engine, when the low-pressure half is erected, will be a compound engine, vertical, with the air cylinders above the steam. The engine works at a steam pressure of 90 lbs.; diameter of high-pressure cylinders 400 millimetres ($15\frac{1}{2}$ inches), diameter of low-pressure cylinders will be 550 millimetres ($21\frac{1}{2}$), stroke 600 millimetres ($23\frac{1}{2}$), diameter of air cylinder 650 millimetres ($25\frac{1}{2}$ inches). The engine delivers the air at a pressure of $1\frac{1}{2}$ to 2 atmospheres. The engine was built by Messrs. Klein of Dalbusch. Between the blowing engine and the converters is arranged an air accumulator or equaliser, with a safety-valve to blow off at two atmospheres."

At Hagen they have made such progress with the process that they are able to produce castings at will (within reasonable limits), having predetermined tensile strength, and on the occasion of the previous visits of Mr. Lange, and at his and the author's joint visits, three casts were made—1st, for mild steel; 2nd, for intermediate steel; 3rd, for hard steel. The very elaborate table of mechanical tests appended will give an idea of the success they have attained in this direction, and also of the quality after forging.

The following tables give the details of the three blows at Hagen, January 19, 1894:—

* The same type of cupola is in use at the Lowca Works.

BLOW I.—For Steel 45 to 50 Kilogrammes Tensile Strength per Square Millimetre.

Time.	Observations.
18' {	12.15 Cupola tapped. Sample 1, pig iron; Sample 2, ferro-silicon.
	12.18 All metal in converter.
	12.28 Slight boil. Vessel rather cold, this being first blow.
	12.33 Blow finished.
2' {	12.34 Sample 3. Blown metal.
	12.35 7 per cent. ferro-silicon poured in from crucible.
	12.37 Blow finished.
	12.38 { Melted ferro-manganese added. Metal left quiet in vessel for four minutes.
	12.42 Sample ingot taken, No. 4 sample.
	12.43 First ladle for casting drawn.

BLOW II.—For Steel 55 to 60 Kilogrammes Tensile Strength per Square Millimetre.

20' {	1.8 Cupola tapped. Pig iron sample taken, see 1.
	1.11 All metal in converter, 550 kilogrammes.
	1.12 Turned up.
	1.28 Blow finished. Sample 5, blown metal.
	1.29 Ferro-silicon put in, 7 per cent. of charge.
1½' {	1.31½ { Afterblow ended, ferro-manganese, &c., added; vessel not turned up.
	Sample 6, small ingot.
	1.43 Metal allowed to stand in converter.
	Commenced casting.

BLOW III.—For Steel 70 to 75 Kilogrammes Tensile Strength per Square Millimetre.

16' {	2.10 Turned up.
	2.19 D line first visible in spectroscop.
	2.20 Green lines visible.
	2.22 Potassium line visible.
	2.26 Blow ended.
2' {	2.27 Ferro-silicon put in, 7 per cent. used.
	2.29 Afterblow finished.
	2.30 Ferro-manganese, &c., added.
2½' {	2.40 Sample 7, cast large ingot.
	2.50 Cast large pinion.
	2.55 Last casting poured. Metal perfectly fluid. No skull in ladle.

It will be noted that the metal from a 12-cwt. charge was perfectly fluid twenty-five minutes after the blowing was finished.

From Mr. Lange's tests it will be seen that—

- No. 1 strength desired was 45 to 50 kilogrammes per square millimetre, and average actual obtained, 47.3.
 No. 2 strength desired was 55 to 60 kilogrammes per square millimetre, and average actual obtained, 56.8.
 No. 3 strength desired was 70 to 75 kilogrammes per square millimetre, and average actual obtained, 67.2.

Also that—

- No. 1 having tensile strength 30.3 tons, gave 25 per cent. elongation in 4-inch specimen from the annealed casting, while the same steel, after forging, gave 35.2 tons strength with 26.5 per cent. elongation in 4 inches.
 No. 2 tensile strength 36 tons, with 0.13 per cent. elongation in casting, and 42.1 tons with 24 per cent. elongation after forging.
 No. 3 tensile strength 42.6 tons with 8½ elongation in casting, and 49.12 tons with 23½ elongation after forging.

It must be admitted that these results are excellent.

The great development of heat, mainly by the combustion of silicon in the afterblow, is very evident in practice, but it is possible to ascertain by calculation what the increase in temperature really is.

Take the Hagen practice.

The charge of metal 12 cwt. = 1344 lbs.

Ferro-silicon added = $\frac{1344 \times 7}{100} = 93$ lbs., and taking it to con-

tain 10 per cent. silicon we have 9.3 lbs. silicon to burn. The specific heat of silicon being 7830, we have $7830 \times 9.3 = 72,719$ units of heat developed; but to burn this we introduce a certain volume of air (O + N), and this has to be raised from say 30° to the temperature of the bath, say 2000° C.

9.3 Si requires $\frac{3}{14} \times 1$ parts O (= 10.6) to form SiO₂.

10.6 oxygen corresponds to $\frac{10.6 \times 77}{23} = 35.4$ parts nitrogen.

The heat required to raise the O to 2000° = $10.6 \times 0.21 \times 2000 = 4452$ units.

„ „ „ N to 2000° = $35.4 \times 0.24 \times 2000 = 16,892$ units.

$4452 + 16,892 = 21,344$ units, which have to be deducted.
 $72,917 - 21,344 = 51,573$ units left for the bath. This has to be divided by 1344 lbs. of metal having a specific heat of 0.16, and the actual increase of temperature is $\frac{51,573}{1344 \times 0.16} = 240^\circ \text{C}$. So

that if the bath had a temperature of 2000° C. before blowing the ferro-silicon addition (which is about the actual fact), it would have its temperature increased to 2240° C. in two minutes by the oxidation of the silicon alone. There is still the effect of the burning of the 3 per cent. carbon and 1.1 per cent. manganese to take count of; but manganese has only a moderate calorific value, and its combustion adds only a moderate heat to the bath, while if the carbon all burns only to CO, its effect would be to slightly reduce the temperature of the bath; if it burns to CO_2 , it will considerably increase its temperature, but at present data are wanting to decide this point.

In this calculation no account has been taken of loss by radiation and convection, which cannot be very serious in the short time of two minutes or less. It is obvious, therefore, why the bath becomes so much hotter and more fluid. The question will naturally arise, are there any other elements available for such a purpose? It is possible that within the limits of practicability phosphorus may perform this function, and Mr. Walrand has pointed this out in connection with the basic process.

Following are details of analyses of the various blows at Hagen, November 28, 1893. Samples taken by Mr. Lange. Analyses by R. Lowe.

	1.	2.	3.	4.	5.
	Sample Drillings from Vulcan Pig Stacked at Hagen as 2-24 per Cent. Silicon.	Sample of Malted Vulcan Pig as Charged into the Converter.	First Blow, Shop No. 51, to give a Soft Steel 43-48 Kilo. gave actually 44.5 Kilo. per Sq. Mm.	Second Blow, Shop No. 52, to give 55-60 Kilo.	Third Blow, Shop No. 53, to give 75 Kilo.
Iron (by difference)	92.27	93.024	98.791	97.972	97.78
Combined carbon . . .	0.24	0.38	0.27	0.31	0.32
Graphite	3.3	3.20	nil	nil	nil
Silicon	2.79	2.143	.288	0.604	1.071
Sulphur	trace	0.046	0.043	0.043	0.023
Phosphorus	0.032	0.055	0.068	0.063	0.086
Manganese	1.368	1.152	0.54	1.008	0.720

Samples taken by Mr. Lange, November 5, 1893. Analyses by G. J. Snelus, jun., A.R.S.M.

	6.	7.	8.
	Shop No. 54, to give Mild Steel 45-50 Kilo., Mean of Two Tests gave 47.7 Kilo. (=80.4 Tons). .	Shop No. 55, to give Medium Hard Steel 55-60 Kilo. gave 58.75 Kilo. as Mean of Two Tests (=84 Tons).	Shop No. 56, to give 70-75 Kilo. gave 68.8 Kilo. (=48.6 Tons).
Iron (by difference) . . .	98.233	97.85	97.03
„ (by experiment) . . .	98.4	97.4	97.10
Combined carbon . . .	0.23	0.27	0.34
Silicon	0.356	0.508	0.838
Sulphur	0.058	0.049	0.048
Phosphorus	0.067	0.069	0.072
Aluminium	0.087	0.150	0.144
Manganese	0.966	1.594	1.513

The following tables give the analytical results of the operations :—

Samples taken at Hagen, January 19, 1894, by GEORGE J. SNELUS and E. J. LANGE. Analyses by GEORGE J. SNELUS, jun., A.R.S.M., and R. LOWE.

BLOW I.

	I.	II.	III.	IV.
Description.	Sample Melted Pig Iron Used.	Sample of Un-melted Ferro-Silicon Employed. Not an Average Sample.	Sample of Blown Metal before adding the Ferro-Silicon.	Sample of Steel intended to give 45-50 Kilo., Actual Test gave 47.8 Kilo.
Iron (by difference) . . .	93.263	82.535 by estimate 82.400	99.833	...
Combined carbon	0.360	nil	trace	0.16
Graphite	3.050	3.14	nil	nil
Silicon	2.090	13.114	0.037	0.335
Sulphur	0.039	trace	0.045	0.040
Phosphorus	0.046	0.130	0.049	0.067
Manganese	1.152	1.08	0.036	0.648
Aluminium . . . . .	...	...	...	...

Description.	BLOW II.		BLOW III.
	V.	VI.	VII.
	Blown Metal from No. 2 Cast.	Finished Steel from No. 2 Blow, intended to give 55-60 Kilo., gave 56·8.	Finished Steel from No. 3 Blow, intended to give 70-75 Kilo., gave 67·2 Kilo. per Sq. Mm
Iron	99·905	...	97·721
Combined carbon	trace	0·265	0·33
Silicon	trace	0·559	0·773
Sulphur	0·043	0·041	0·039
Phosphorus	0·052	0·064	0·058
Manganese	trace	0·756	1·008
Aluminium . . . . .	...	...	0·071

It will be noticed that at Hagen it is the practice to finally harden the steel by an addition of ferro-silicon with ferro-manganese, and that they depend more upon the silicon than the carbon for getting the desired strength. For many purposes, and especially for castings, such steel is no doubt very useful, but the author doubts whether it is suitable for use where it may have to stand sudden shock. This departure from ordinary practice is interesting, but, as the Paris experiments show, it is no part of Mr. Walrand's process, but has been worked out at Hagen, and the very high tensile tests obtained and certainty of results is very remarkable.

With regard to the cost of the process, this will vary with the locality and conditions of working. The additional cost of the ferro-silicon is small, and can easily be calculated by those having a knowledge of the Bessemer process.

The cost of these blows of January 19, 1894, irrespective of general working expenses, is stated by Mr. Daelen to be as follows:—

These three blows considered as the work of half a shift=six hours. Casting and fettling the converter took half an hour, so the rate of working was 1 blow per hour. For continuous work, therefore, the cost would work out less.

Note.—1 mark=1 shilling.

Items.	Cost in Marks.	s.	d.
Leading hand	3	=	3 0
Engineman	1 60	=	1 7½
Two labourers	4 00	=	4 0
Hoisting of pig iron and coke for cupola	2 00	=	2 0
Maintenance of cupola wages	4 30	=	4 3½
converter	6 00	=	6 0
450 kilogrammes coke=18 per cent. weight of pig would be but 10 per cent. in continuous working	7 05	=	7 0½
2400 kilogrammes pig iron Vulcan hæmatite from Duisburg (2½ per cent. silicon) at 54 marks per 1000 kilos.	129 60	=	129 7½
Steam used	5 00	=	5 0
Warming of the converter with wood	75	=	0 9
Fettling material for cupola	75	=	0 9
" converter	1 40	=	1 5
	165 45	=	165 5½
To be deducted 650 kilogrammes superfluous pig melted, say now worth 50 marks per 1000 kilos.	32 50	=	32 6
	132 95	=	132 11½
The additions ferro-silicon, ferro-manganese, &c.	7 40	=	7 5
	140 35	=	140 4½

Weight charged into converter 550 kilogrammes+600+600 kilogrammes=1750 kilogrammes = 1750-280 kilogrammes (=16 per cent. waste in converter)=1470 kilogrammes+80 kilogrammes from additions=1550 kilogrammes steel.

Therefore—

1550 kilogrammes at 140 35 marks=1000 kilogrammes at 90 50 marks, or say 90 shillings per ton=4s. 6d. per cwt.

∴ 4s. 6d.=price of 1½cwt. of the steel as it stands in the ladle.

An approximate estimate of cost of hornblock exhibited is as follows:—

	Marks.	s.	d.
Material in ladle per 100 kilogrammes	9 0	=	9 0
Loss of all kinds of hornblock castings	2 0	=	2 0
Moulders' wages	2 50	=	2 6
Materials and utensils	2 00	=	2 0
Annealing	1 00	=	1 0
Fettling and cutting off runner and risers	3 00	=	3 0
Wasters, carriage, labourers' work, &c.	2 00	=	2 0
	21 50	=	21 6

=21 50 marks per 100 kilogrammes (say 21s. per 2 cwt., about=10s. 6d. per 1 cwt.).

Weight of casting, plus runner and risers=88 kilogrammes.

 " minus " 70 "

With regard to the cost of a complete installation, Mr. Daelen states that the total cost of the buildings and plant complete at Hagen would be about £3500, and gives the following details:—

Blowing-engines as completed for blowing	£750
Blast-pipes and accumulator	75
Two converters of 600 kilogrammes capacity	300
Cupola, stage, and hoist	250
Boiler, tubular	400

In most foundries, buildings, cupolas, steam service, &c., would be available, and the main items of cost would be the blowing-

SMITHYING TESTS of Metal for Steel Castings made at the

Shop No. of Blow.	Distances between Centres on the Tonsile Test-piece.	Diameter of Test-piece.	Corresponding Section.	Total Load at which Test-piece broke.	= Kilos. per Square Inch.	Tons per Square Inch.	Final Length (former)		REMARKS.
							8 Ins.	4 Ins.	
51	$\left\{ \begin{smallmatrix} 4 \\ 2 \end{smallmatrix} \right\}$	·652	·333	10·52	49·8	31·56	...	5 $\frac{1}{100}$	the hardened sampled that of wrought iron.
52	$\left\{ \begin{smallmatrix} 4 \\ 2 \end{smallmatrix} \right\}$	·652	·333	13·56	64·2	40·68	...	4 $\frac{2}{100}$	
53	2	·652	·333	14·63	69·3	43·89	...	...
54	$\left\{ \begin{smallmatrix} 4 \\ 2 \end{smallmatrix} \right\}$	·798	·500	16·97	53·6	33·94	...	5 $\frac{1}{100}$	the hardened sampled that of wrought iron.
55	$\left\{ \begin{smallmatrix} 4 \\ 2 \end{smallmatrix} \right\}$	·798	·500	20·17	63·7	40·34	...	4 $\frac{2}{100}$	
56	$\left\{ \begin{smallmatrix} 4 \\ 2 \end{smallmatrix} \right\}$	·798	·500	24·7	78·0	49·4	...	4 $\frac{7}{100}$	
57	$\left\{ \begin{smallmatrix} 8 \\ 4 \\ 2 \end{smallmatrix} \right\}$	·798	·500	17·61	55·6	35·22	9 $\frac{67}{100}$	5 $\frac{1}{100}$	the hardened sampled that of wrought iron.
58	$\left\{ \begin{smallmatrix} 8 \\ 4 \\ 2 \end{smallmatrix} \right\}$	·798	·500	21·07	66·5	42·14	9 $\frac{51}{100}$	4 $\frac{2}{100}$	
59	$\left\{ \begin{smallmatrix} 8 \\ 4 \\ 2 \end{smallmatrix} \right\}$	·798	·500	24·56	77·6	49·12	9 $\frac{1}{100}$	4 $\frac{2}{100}$	

TESTS OF CAST PIECES of Metal for Steel Casting

Date of the Trials.	Where these Mechanical Tests were made.	Shop No. of Blow.	Distances between the Centres on Tensile Pieces.	Diameters of the Test-piece.	Its corresponding Section =	Total Breaking Load.	
Nov. 28, 1893, Hagen in Westphalia.	Hagen in Westphalia.	51. Pieces were cut from 2 horn-blocks	100 mm. = 4 inches and	17.1 mm. = .660 inches	230 sq. mm. = .342 sq. in.	} 10,250 9,650	ture. The partly crystalline. Slight due to a
			50 mm. = 2 inches for both	16.45 mm. = .622 inches	212 sq. mm. = .304 sq. in.		
Dec. 5, 1894, Hagen in Westphalia.	Hagen in Westphalia.	54. 2 pieces from test-block	100 mm. = 4 inches and	} 12.8	129	6,200	two pieces were. Both free from a
			50 mm. = 2 inches for both				
		55. 2 pieces from test-block	100 mm. = 4 inches and	} 17.4	238	12,650	were partly crystalline, a prepon-
			50 mm. = 2 inches for both				
		56. 2 pieces from test-block	100 mm. = 4 inches and	} 17.08	228	12,400	showed a
			50 mm. = 2 inches for both				
Jan. 19, 1894, Hagen in Westphalia.	Gorton Foundry.	57. 4 pieces from test-block	Inches. 8	Inches. .798	Square In. .5	Tons. 14.73	piece was one of the second was and 2 inches fracture the other fibrous.
			8	.798			
			4	.798			
			2	.798			
		58. 3 pieces from test-blk.	8	.798	.5	17.25	three pieces extent crystalline the most appearance.
			4	.798			
			2	.798			
		59. 3 pieces from test-blk.	8	.798	.5	21.42	appearance in pieces had
			4	.798			
			2	.798			

engine and converter. The mechanical turning-gear for converters used at Paris, Le Creusot, and Hagen is simple and inexpensive, and answers admirably. The advantage to an ironfounder to be able to make steel castings cheaply, just when wanted, as easily as those of cast iron, and even in green sand, is so apparent, that in all probability no foundry of importance will in future be considered as properly equipped without a Bessemer converter.

Although the chief aim of the inventors of this process has been to facilitate the manufacture of steel castings suitable for ordinary iron foundries, it by no means follows that it is not applicable to other purposes; and the author believes that it will be useful in all cases where quality of product is of more importance than a slight extra cost. If, for instance, it is possible by this process to make a sound soft steel of uniform quality without blow-holes, why should it not reinstate the Bessemer process for the manufacture of plates? In examining a vast number of fractures of tensile tests of plate steel, the author has rarely failed, with a powerful lens, to detect indications of want of continuity in the metal, due to gas cavities, even in samples of Siemens steel; and all such defects must involve irregularity, and possibly failure; so that if this process will largely eliminate gas cavities and give a sounder steel, the slight extra cost of the process should be more than compensated by the improved quality of the material. It is also possible by this process, with careful attention to the quality of the materials employed, to make steel of all grades of hardness equal in quality to *crucible* steel.

Before concluding this paper the author desires to record his thanks to all who have so generously assisted him with information, and desires especially to mention Mr. Müller of the Hagen Steelworks, Mr. H. Schneider and Mr. Bouvard of Le Creusot, Mr. E. F. Lange of Gorton Foundry for his elaborate mechanical tests, and Mr. Hall of the Lowca Works, who has kindly furnished the diagrams.

In conclusion, the author desires to point out that although this invention is of French growth, it has already taken root in Germany and even in Spain, and surely English steelmakers and founders cannot afford to ignore it. If this paper should have the effect of starting its growth in this country, the author's object will be attained.

DISCUSSION.

Mr. WALRAND expressed his concurrence with the facts detailed in the paper.

Mr. E. F. LANGE wished to thank Mr. Snelus for the kind way in which he had acknowledged the slight service it had been his privilege to have rendered in connection with the preparation of this paper. He wished to add a few remarks on the discussion which had taken place, and that purely in his capacity as a private member of the Institute. Mr. Snelus had drawn attention to the interesting character of the analysis of the metal as made at Hagen. The metal from which the test pieces were taken had all been annealed for a period of four days in an ordinary grate-furnace. The general results of the testing were in the highest degree satisfactory. The metal, even in the softest grades, showed a very fine grain fracture when broken transversely, and was perfectly free from blow-holes. What slight faults revealed themselves in certain test-pieces, were evidently due to the manner of casting, the metal being teemed somewhat too hot, and without a bottom stopper in the ladle. Some of the tests, particularly the forging tests, were truly remarkable. The welding tests were hampered by a want of sufficient metal to test with, and it did not follow that they were the best which could be obtained; those recorded, however, were sufficient to show what the metal was capable of in that respect. It was observed that a re-welding was generally better than the first welding, and this was probably due to the diminution in the silicon and manganese contents at that temperature. The re-weld in the case of blow 57 gave 34.53 tons per square inch tensile strength instead of the 27.60 tons recorded in the tables, or only about half a ton less than that of the forging test. Among the samples would be noticed forged bars of the softer metal, which, on quenching from an orange-red heat, and breaking transversely, showed a fibre curiously similar to that of a good wrought iron bar. The slight increase of strength, all things considered,

which forging afforded on the material was proof of its initial soundness.

The manager at Hagen, who had since left to fill an important post at a steel works in Silesia, said that he preferred to harden his steel for casting by combining with silicon and manganese rather than with carbon, as, when carbon was present as the sole element in quantity, it was liable, in the presence of oxide of iron, to occasionally affect unfavourably the molecular structure of the steel. It was probable that all views as to the expediency of considering any element but carbon necessary in steel would become modified by a proviso regarding the extent to which iron oxide might be present; and now that simpler means were at hand for estimating iron oxide, this would be far more frequently done than formerly, and would doubtless explain many apparent inconsistencies in chemical analysis. The softest grain of metal, as represented by blow 51, appeared to be most suitable for locomotive wheel centres. On looking up an analysis, which he once made of some turnings of a locomotive wheel centre, cast from crucible steel, and of a quality he had not known surpassed, he was considerably interested to find how closely it approached the analysis made in the case of blow 51. Mr. Snelus's figures gave combined carbon, 0.27; silicon, 0.28; manganese, 0.54. The analysis in question gave combined carbon, 0.26; silicon, 0.26; manganese, 0.45. The mechanical tests were also as similar. With regard to the taking up of this process by users of steel castings, there was no doubt that in view of the gradual replacement of iron by steel in the cast portion of machine and other structural work, many firms would sooner or later seriously consider the advisability of becoming their own producers by extending their plant for this purpose; and their decision would not be wholly influenced by the question of cost, for, as many possessors of iron foundries would admit, there were advantages gained by having absolute control of the casting work which ranked equally with wholly commercial ones. To such firms, too, the clear explanation by Mr. Snelus of the advantages and practicability of the Walrand-Légénisiel process for their purposes, would be in the highest degree interesting, and would enable them, in their possible lack

of such an especial knowledge, to better understand the principles involved. The user of steel castings desired some means of manufacturing himself, which would have the advantages of the cupola in the iron foundry, and from all he saw of the working of the process at Hagen, it could not but be admitted that the small converter thus worked fulfilled, in a large degree, this condition. Its capacity suited itself to the demand. It could be set in and out of work at once as required. The cost of maintenance when out of working was trifling, and from this circumstance, the average cost would not unlikely strike a lower one than that of even a small open-hearth furnace, which had to be kept constantly in heat. Cold heats, with their accompanying risks, were an impossibility, and the first heat of a series was equally good as the last. The nine heats recorded in the tables were the only nine heats which they had had between the dates of the experiments, as, being slack of work, they found it better to work their crucible and open-hearth plants to advantage (having ingots for spring steel and having common castings always on order), than two separate plants at a disadvantage. The process could be worked with certainty of result, and the metal could be altered at every small change to suit any class of casting, and the claim made that its quality was equal to that of soft crucible metal was borne out by the tests which he made to determine the accuracy of this assertion. The especial conditions, therefore, for the successful manufacturing of steel castings on a small scale, would appear to be well fulfilled by the Walrand-Légénisel process.

Sir BERNHARD SAMUELSON, Bart., Past-President, thought that if all that was promised by this process was fully confirmed in practice, it would be a most valuable one for the production of small castings, such as were used by agricultural and other engineers, and the metal would form a most useful substitute for the very uncertain malleable castings now used for those purposes. The cost of malleable castings was considerable, and the process by which they were produced involved difficulties and risks, the result of which was very frequently great disappointment in the product. He certainly thought the process described was one deserving the careful

consideration of those who were producers and users of castings of this description. He would like to give his thanks to Mr. Snelus, and the gentlemen who had been associated with him in the production of the paper, for the very frank exposition which they had made of all the elements involved in the process. He remembered some seven or eight years ago Mr. Nordenfelt exhibited some very remarkable castings at a meeting of the Institute, but when he was pressed to divulge the process by which they were produced, he did not comply with the request which was made to him to that effect. He believed that in his reticence Mr. Nordenfelt made a mistake, not only in the interests of the trade but in his own, and that process had now almost entirely ceased to be spoken of. It had never been used to any great extent. The whole matter was involved in a mystery, which was not what they, as members of the Institute, were accustomed to in regard to inventions which were brought before them. If all gentlemen producing new processes would act with the same candour with which these gentlemen had acted, he thought it would contribute to their own advantage, as well as to the credit of the Institute before which the papers were read.

Mr. R. M. DAELEN said that when he was invited by Mr. Walrand to see this new process in Paris, he recognised directly that the method was a very suitable one for making castings, because it made them of a character nearly like crucible steel; and in that way the metal could be distinguished from the soft metal made in the basic open-hearth or in the acid open-hearth. He saw the foundry of Mr. Schneider, where they employed moulds of green sand, and where they got very good castings. He had encouraged his friends in Germany to introduce this new process, and to adopt it at Hagen, where, as Mr. Snelus had stated, it was working very well. He tried to introduce the process further, but he very often met with the objection from steelmakers in Germany, that this process carried on in small Bessemer converters would be very much dearer than the process which was carried on in open-hearth furnaces. That might be true. If the open-hearth furnaces could be kept working day and night, and had a very large output, the liquid metal might be cheaper than that produced by a small

Bessemer converter; but if they considered the difference between the cost of the liquid metal and the price of the finished castings, they would find that the difference was nearly double. The most important thing was to have a metal very suitable for making castings, because if the metal was not suitable then the cost would ultimately be augmented. The most important point in connection with this new process was, that it furnished a method of producing in small quantities, and in small converters, a metal very suitable for castings. It might be said that it would not be so important for converters of greater content—say, over 2 tons—but he thought that in many cases it was a very good thing to have a method of regulating the temperature in a very easy manner, because the quality of the liquid metal always depended in a very high degree upon the temperature obtained at last. In this process there was a very simple method of regulating the temperature.

Mr. JAMES RILEY, Vice-President, wished to ask a question. If the small converter was so very suitable for the operations at Hagen, one would have thought that when they were slack of work it would have been most useful. Why then did they stop the converter and work the crucible and the open-hearth furnace?

The PRESIDENT was afraid the reply to that question would not give any information with regard to the subject of the paper. It appeared to him that Mr. Snelus had brought before them a system of making small castings, which, as Sir Bernhard Samuelson pointed out, would undoubtedly be useful, especially for agricultural purposes. By adopting the small converter they had a handy tool, and were able to make steel of any degree of softness; and by the addition of silicon at the end of the blow, and continuing the operation, they got a very high temperature, and so were enabled to make many castings without skull. Those were the main points of the paper. He was sure they were much indebted to Mr. Snelus for bringing the matter before them so ably and carefully, and would be quite ready to accord him a hearty vote of thanks.

The vote of thanks was carried by acclamation, and the following paper was read:—

SCANDINAVIA AS A SOURCE OF IRON ORE SUPPLY.

BY JEREMIAH HEAD, M.Inst.C.E., LONDON.

SWEDEN and Norway have been known as iron-producing countries for several centuries. Swedish charcoal pig iron, and Swedish bars of great purity, have long been imported into this and other countries; but, on account of their costliness, they have been used but sparingly, and only for special purposes. This industry still holds its own. Pig iron to the extent of about 500,000 tons is annually produced at Orebro, Kopparberg, and elsewhere (see Plate IV.), from about 1,000,000 tons of the rich ores of the Central and Southern Provinces; and the greater part of this is further worked into finished iron and steel. The total number of persons employed in these Swedish industries is about 35,000.*

A similar trade exists, but to a very small extent, in Norway. When there in 1891, I found that only one blast-furnace remained at work in the whole country, namely, that at Naes, near Grimstad. It worked in winter only, producing then 75 to 100 tons per week of charcoal pig iron. The summer was spent in cutting down timber and preparing a stock of charcoal. The ore used was self-fluxing, obtained from local magnetite mines. It contained about 50 per cent. of iron, and produced a pig iron in which the phosphorus amounted to 0.035 per cent.

But although pigs and bars have long been known as Scandinavian products, iron ore was never regarded as an important article of export until comparatively recent times.

Between 1870 and 1887, the total iron ore exports from Sweden varied from 9485 tons in the former to 41,765 tons in the latter year.† Of the 41,765 tons, only 657 tons found its way into the United Kingdom. The same year we received from Norway 2485 tons. The bulk of the Swedish iron ore then exported was from

* *Journal of the Iron and Steel Institute*, 1893, No. I., p. 438.

† See Table I. These export and import statistics are all derived from official sources.

the Grängesberg mines, situated in the southern part of the peninsula, and was sent to Germany for the manufacture of basic pig iron. In 1887, therefore, the British iron trade was deriving from Scandinavia only about 3000 tons of iron ore. But before dealing with the six years following 1887, I desire to say a word about those antecedent to 1870.

About 1867, Mr. Thomas Snowdon, of Middlesbrough, bought a magnetite mine situated on the seaboard a little to the north of Gefle, and imported two cargoes of ore containing 66 per cent. of iron and only a trace of phosphorus. One of these cargoes was sent to the furnaces of Messrs. Cochrane & Co., and the other to those of Messrs. Hopkins, Gilkes & Co. Mr. Snowdon says that the lower down he quarried, to a depth of 25 feet, the richer in iron and freer from phosphorus he found the ore.

Notwithstanding that steamers carrying 1000 tons could lie so close in to the mines that the ore could be wheeled right aboard, the cost of production and delivery at that time were higher than the price obtainable, and consequently the mine was abandoned.

About the year 1868 a company called the Titanic Iron Company (Limited) leased two old furnaces at Norton, near Stockton, and there made, at the rate of about 200 tons per week, what they called Titanic pig iron. The mineral used was in part titaniferous ore obtained from a deposit near Soggendal, on the south-west coast of Norway (see Table II., column 13), and in part Spanish, Algerian, and Elban hæmatites, and Irish bog ores. The proportions varied according to the product desired. The molten metal was run into iron moulds, and was sold for high-class purposes, principally in the Leeds and Sheffield markets. The titaniferous ore was at first found difficult to smelt, but that difficulty was eventually entirely overcome by the adoption of suitable mixtures. The titanic pig iron contained from 0.038 to 0.185 of phosphorus, and up to 3 per cent. of titanium. The slag contained up to 3 per cent. of titanic acid.

The Titanic Iron Company, after a fairly successful career of six or seven years, was compelled to suspend operations, owing probably to the advent of steel, and the Norton furnaces have been inoperative ever since.

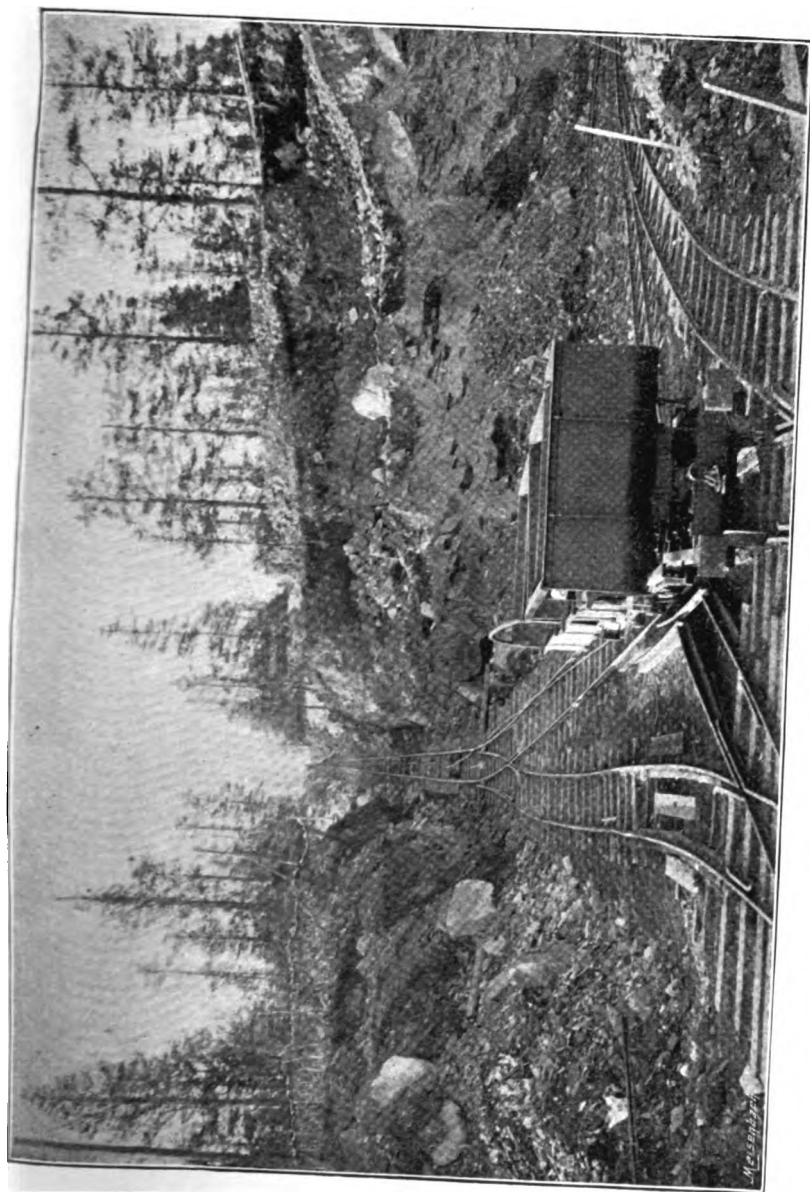
I will now revert to the position at the end of 1887. During



PLATE VI.

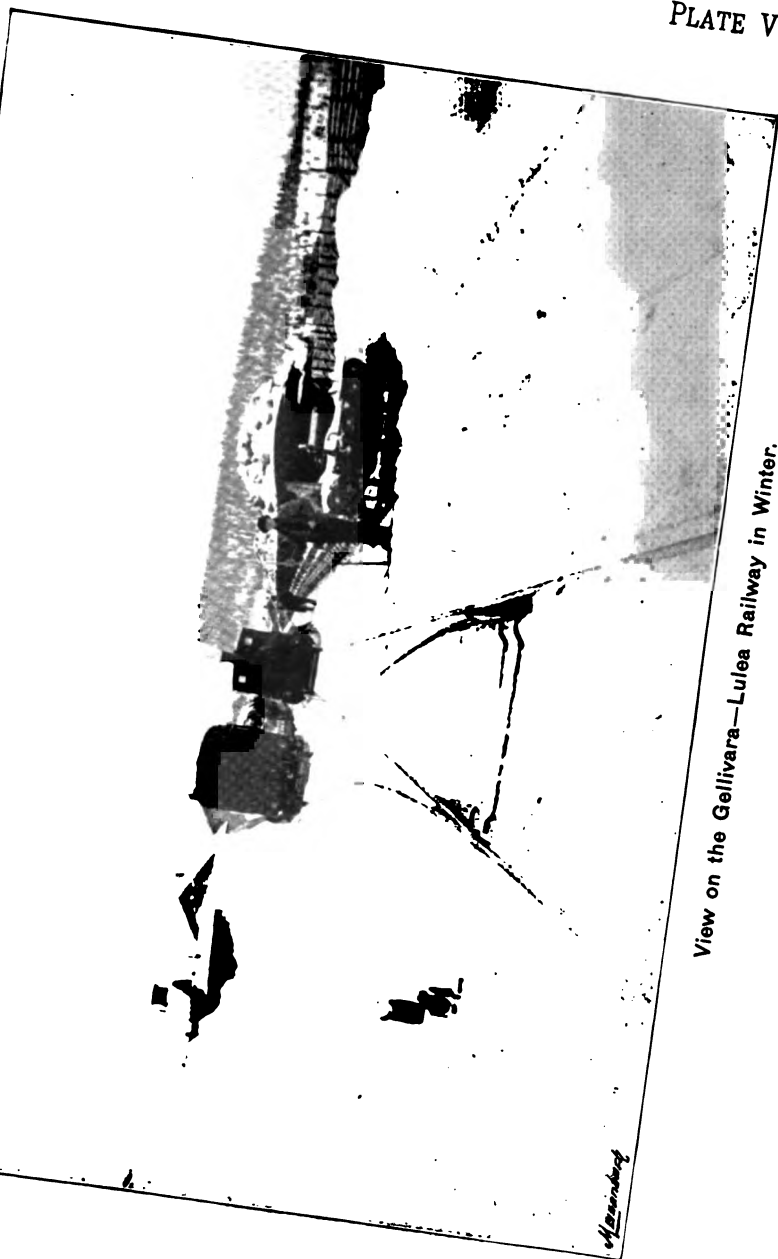


One of the Gellivara Magnetite Quarries.



Incline and Magnetite Quarry at Gellivara.

PLATE VIII.



View on the Gellivara—Lulea Railway in Winter.

the year 1888 Great Britain received from Norway only 720 tons of iron ore, and the imports from that country to the United Kingdom have ever since been quite insignificant. With Sweden, however, the case is altogether different.

In 1888 the total exports rose from 41,765 (the figure for 1887) to 117,530 tons, and those to the United Kingdom from 657 to 62,672 tons. This sudden increase was due to the operations of an English company called the Swedish and Norwegian Railway Company (Limited), which had during the previous year made a railway 132 miles long from the iron ore deposits at Gellivara, in Swedish Lapland, to Lulea, a seaport on the western shore of the Gulf of Bothnia. This company had acquired a concession granted by the Swedish and Norwegian Governments conferring the right to carry a railway right across the peninsula, the total distance authorised being $308\frac{1}{2}$ miles. The concession included also the right to work and export iron ore from the deposits at Gellivara, Kirunavara, Luossavara, and Svappavara, which lay on or near the selected route, at a royalty of from 6d. to 8d. per ton.

Another company, called the Anglo-Scandinavian Steamship Company, closely allied with the railway company, was established to purchase steamers and convey the ore to British and other ports; and a third, called the Magnetic Iron Mountain Smelting Company (Limited), was formed to take on rental and work two blast-furnaces at Walker-on-Tyne, belonging to Messrs. Bell Brothers (Limited). Most of the ore at that time raised was sent to these furnaces to be smelted. The result was, however, disappointing. The pig iron produced contained from 0·3 to 0·6 per cent. of phosphorus, and was, of course, quite unfit for acid steel-making. As such pig iron for any other purpose was not largely in demand, and if it had been, could have been more cheaply produced by a mixture of Cleveland and hæmatite ores, the Walker enterprise did not result in success. This affected the interests of the allied companies so adversely that they too were presently obliged to discontinue operations.

But the Gellivara mines were found to yield, not only such phosphoric ores as were sent to the Tyne, but also from certain of the workings, a proportion of ore of exceptionally rich and pure quality. A small cargo of this was ordered by Messrs. W. Whit-
1894.—i.

D

well & Co. of Thornaby, and on delivery was found to be so good, that the following telegram was sent by them to the sellers, and, as might be expected, no special pains were taken to hide its contents from the public gaze. Messrs. W. Whitwell & Co. said:—"We have used your first cargo of Gellivara ore for Siemens and Bessemer steel purposes, and find it both wonderfully pure in analysis and to work easily and most advantageously in the blast-furnace. We anticipate for it a great future. Please send us a further 8000 tons this season."

Herr Fried. Krupp of Essen also had a trial cargo of 1000 tons. He found it highly satisfactory for steel purposes; it smelted easily, and the consumption of coke was lower than with ordinary steel ores.*

But notwithstanding these encouragements, it proved impossible at that time to obtain any considerable quantity of mineral of equal quality with the sample lots; and no more was sent. Indeed, very soon after, Gellivara ores ceased to be exported or raised at all; and the shareholders of the Gellivara companies had good reason to regret that those enterprises had ever been brought under their notice.

As a result of this unfortunate collapse, the imports of Swedish ore into the United Kingdom fell from 62,672 tons in 1888, to 15,427 tons in 1889, 5534 tons in 1890, and to 3108 tons in 1891; and, as far as this country was concerned, the Gellivara mines might just as well have ceased to exist.

But the Swedish Government did not regard with complacency the total abandonment of the enterprise. The Riksdag and the people generally had never looked with favour on the acquisition of property rights in their country by foreigners. It had been reluctantly permitted in the present case, in order that the feasibility of the enterprise, of which many Swedes had serious doubts, might be proved at the expense and risk of the more trustful and sanguine British investor. The English company received little or no official encouragement. On the other hand, it encountered much covert opposition, which contributed not a little to the unfortunate result.

* See prospectus of the S. & N. R. Co. issued by Sheppards & Co., 57 Old Broad Street, E.C., October 5, 1888.

Then the Government took over the railway into their own hands, and, after a time, granted very favourable rates to a powerful Swedish company, which forthwith began to work the mines. The English company had made the mistake of mixing (as a rule) the products of the various quarries, thus producing an average quality, which was neither pure enough for acid, nor phosphoric enough for basic processes.

The Swedish company, profiting by the experience of their predecessors, and guided by good mining engineers, took care to keep separate the products of the various workings, and to grade them according to the phosphorus contained, as periodically ascertained by analysis. They established four grades, A., B., C., and D., grade A., intended for acid processes, containing about 69 per cent. of iron and 0.01 per cent. of phosphorus, and grade D., intended for the basic Bessemer process, containing about 65 per cent. of iron and 1 to 2 per cent. of phosphorus. Ore containing appreciable phosphorus, but not enough to render it unfit for acid purposes, was called grade B., whilst grade C. comprised all between that and grade D.

The yield of the quarries, of which there are 131, carefully sorted in this way, was found to be composed of grades A. and B. to the extent of 20 per cent., whilst 80 per cent. belonged to the lower grades.

The effect of these improved arrangements soon began to be apparent. The imports of Swedish iron ore into the United Kingdom gradually rose from 3100 tons in 1891 to 13,722 tons in 1892 and 35,601 tons in 1893. Almost all this was of A. quality, and was delivered to furnaces in the Cleveland district, at prices averaging 18s. per ton. The imports during the present year are expected to reach 130,000 tons.

The general verdict of those who have tried it is that the guaranteed standard of richness and purity has, so far, been well maintained. Table II., column 1, gives the average of seven analyses made by Messrs. Pattinson & Stead from as many cargoes. It is no matter of surprise that much larger quantities have been purchased for the current year. One company alone has contracted for 50,000 tons of A. grade; and it is to be noted that grade D. has to some extent been used in the manufacture of basic pig iron.

That Continental iron companies have been still more enterprising than their English competitors in utilising the new source of iron ore supply, will be evident from the statistics of total exports from Sweden.

From 1888, when they were 117,530 tons, they rose			
In 1889	to	118,571	..
„ 1890	„	187,382	„
„ 1891	„	174,148	„
„ 1892	„	320,871	„
And in 1893	„	447,931	„ *

In other words, since 1887, when the Gellivara-Lulea Railway was completed, to December 1893, the total annual exports have increased by over 400,000 tons, of which 35,000 tons came to the United Kingdom, and the remainder went mostly to Germany and Austria.

Inasmuch as in the last-named countries the great bulk of the steel manufactured is by the basic process, whereas the exact reverse is the case in Great Britain, it is only natural to expect that what is sent to them should be mainly grade D., and that what is sent over here should be mainly A. grade; and this is in accordance with the actual facts of the case.

Mr. Paul Kupelwieser has been good enough to send me his experience at the Witkowitz Works from the year 1888 until he resigned his position as general manager in the spring of 1893. He says that during those five to six years he always used Swedish magnetites from Gellivara and elsewhere (probably Grängesberg, see Table II. column 6) to the extent of about 60,000 tons per annum. They contained from 61 to 64 per cent. of iron, and cost from 22s. to 24s. delivered at Witkowitz. He mixed them in the raw state, in the proportion of from 33 to 66 per cent., with other ores, mostly spathic, and calcined. Used in this way, there was no difficulty in smelting. The resulting pig iron was taken in a molten condition to a Bessemer converter, and, after being partially blown, to a basic-lined Siemens furnace, there to be finished into steel.

Grade D., Gellivara ore, is also now extensively used at the large steel works in Upper Silesia. The port of entrance in this, as in the previous case, is Stettin, whence it is forwarded by rail.

* Statistics supplied by the Board of Trade, March 9, 1894.

The Westphalian Works are users of the same grade. It reaches them *via* Rotterdam, some going forward by Rhine navigation, and some by rail. From Rotterdam to Ruhrort by water costs from 1s. 6d. to 2s. per ton. From the same port to Oberhausen by rail costs 2s. 6d., and to Dortmund 3s. 8d. per ton.

I also have information to the effect that grade D. is now being offered at about 15s. 6d. per ton, delivered in trucks at Antwerp, for use in the Liège and Luxemburg districts.

It will now be obvious to all that during the last six years Scandinavia has become a most important source of iron ore supply to the principal iron-producing countries of Europe. The ore travels about 1680 miles to English (Cleveland), and 1690 to German (Dortmund) works, and 1400 miles to Witkowitz. This is farther than from the celebrated Lake Superior Mines to the Pennsylvanian Steelworks. Only very rich ores could bear such cost for transit.

The value of grade A. ore, containing 69 per cent. of iron and 2 per cent. of silica, is at present about 18s. 6d. per ton delivered at Middlesbrough furnaces. Spanish Rubio ore, containing 50 per cent. of iron and 8 per cent. of silica, costs 12s. 6d. per ton, or 6s. per ton less. But the extra 19 per cent. of iron is worth, at say 5d. per unit, 7s. 11d. per ton, and the 6 per cent. less silica, at say 1½d. per unit, is worth 9d. per ton. Adding these figures and deducting the 6s., we obtain: 7s. 11d. + 9d. - 6s. = 2s. 8d., as the equivalent of the advantage of grade A. over Rubio ore to the extent it is used. In other words, the use of A. grade ore, under present conditions, should enable smelters to cheapen the cost of production of pig iron for acid steel purposes to a substantial extent.

It should be of further assistance in this way. There are certain hæmatite ores which have been submitted to a washing process to clear them from the matrix in which they are found embedded.

The effect of washing is to increase the percentage of all the remaining elements. A sample of washed and dried Rubio ore from the San Salvador mines, near Santander, analysed for me by Messrs. Pattinson and Stead, contained 59·5 per cent. of iron, 0·038 per cent. of phosphorus, and 1·7 per cent. of silica.*

* The same ore in the cargo yields 51 to 52 per cent. of iron, as compared with 48·5 to 49·5 per cent., which is now an ordinary yield for Bilbao ore.

By itself, such an ore could not be used without exceeding in the pig iron the phosphorus limit permissible for acid steel purposes; but by mixing it in the charge with grade A. Gellivara ore containing say only 0.01 per cent. phosphorus, it can be made available and benefit obtained from its high percentage of iron, and from its somewhat lower market value, due to the excess of phosphorus.

Rubio ores containing an excess of silica can be utilised in a similar way by mixing with grade A. Gellivara, or even with B. grade.

For the manufacture of pig iron for acid steel processes, there seems to be no doubt whatever but that a valuable new material has now become available in grade A. Gellivara magnetite ore. The large and growing importations into Germany, and the five to six years' experience at Witkowitz, seem also to afford sufficient proof that grade D. is equally of value in the manufacture of pig iron intended for the Bessemer basic process as carried on in those countries.

The question remains, how far can we in England use to advantage grade D., with or without our native phosphoric ores, and with or without puddlers' tap, in making pig iron suitable for the Bessemer basic process?

That pig iron made solely or mainly from Cleveland native ores can be turned into good steel in a basic-lined Bessemer converter, the daily practice of Messrs. Bolckow, Vaughan & Co. (Limited) and others has long ago proved.* But that is not the whole question. What is wanted is not only good basic steel, but good basic slag for manure. The by-products are indeed as important commercially as the main products, and the market value of them seems to be increasing day by day. The old stock of puddlers' tap containing an average of say 52 per cent. of iron, 17 per cent. of silica, 1.0 per cent. of sulphur, and 3.25 per cent. of phosphorus (see Table II. column 7), is nearly exhausted, and the current output is steadily diminishing. During the twelve years 1882-93, the production of puddle bar in the United Kingdom has decreased by 53 per cent., and in the Cleveland district by 73 per cent.†

* *Proceedings of the Institution of Mechanical Engineers*, 1893, pp. 245-246.

† *Iron and Coal Trades Review*, March 30, 1894, p. 399.

The diminution in the production of puddlers' tap must have been in the same proportion. Will grade D. prove a satisfactory substitute? That is a question which time and experience can alone fully determine. But it is clear from the analysis (see Table II. column 2) that it promises well as a source of iron and phosphorus, without the drawbacks of high silica and sulphur. Much depends on the price at which it can be delivered. To this point I will again refer.

The Gellivara deposits (see Plate V.) are 4 to 5 miles long by 1 to 2 miles broad. The ore in sight, or which can be detected by the dip-needle, covers an area of 160 acres. Borings have been made to a depth of 175 feet without reaching the bottom. The quantity of ore has not been determined, but there is no doubt that it is enormous; indeed, enough to supply all probable demands for several generations.

As a material for the manufacture of pig iron for acid steel purposes, there is obviously an advantage in the use of grade A. ore at present prices. But the market value of such pig iron is now about 9s. per ton more than that of Cleveland or of Cleveland basic pig iron.

The puddlers' tap, which forms so important an ingredient in the last-named commodity, is selling at about 6s. 6d. per ton delivered to smelters.

For a time at least this will have to be taken into account in determining the value of grade D., and deciding whether it can be profitably imported into this country.

A similar question arises in respect of grade C. as a material for use in the production of ordinary Cleveland pig iron for forge and foundry purposes. Will it displace native ore partially or entirely? Let us consider.

The cost of the calcined Cleveland ironstone necessary for the production of a ton of Cleveland pig iron is about 15s.*

If this were displaced by Gellivara ore yielding 65 per cent. of iron, $1\frac{1}{2}$ ton would obviously be required. At the same total

* To the extent that Cleveland calcined ore is displaced by puddlers' tap in making basic pig iron, the total cost for iron-producing mineral would be reduced in the proportion of 15s. to 6s. 6d. $\times \frac{2}{3} = 11s. 4\frac{1}{2}d.$ per ton of pig produced. But in that case, manganese ores, the use of which tends to raise the cost, must be added to neutralise the sulphur.

cost, viz. 15s. per ton of pig produced, this would admit of the price of two-thirds of 15s., or 10s. per ton of ore delivered to the furnaces, being paid for it. Inasmuch as in the case of the richer ore there would be less earthy matter to melt into slag—time, fuel, and establishment charges being presumably saved thereby—and inasmuch as the resulting pig iron would certainly contain less phosphorus, and would therefore be better and more valuable for many purposes, a somewhat higher price might be obtainable for grade C. ore than that just mentioned. But these consequential gains are to some extent problematical, and time must elapse before they are generally admitted.

Can grade C. be delivered to Cleveland furnaces for 10s. per ton, or any near approximation thereto?

If so, its advent seems imminent. If not, it may have to wait.

According to custom-house returns, the lowest average value of iron ore imported from Sweden into the United Kingdom since 1888 is 16s. per ton.

Mr. J. T. Smith, Past-President, who visited Gellivara in 1888, considered that when the output reached 1,500,000 tons per annum, the cost of raising, conveying, and putting f.o.b. at Lulea would not exceed 5s. 6d. per ton, including royalty and some other charges.* But as the output has not yet reached one-third of that quantity, and as all charges have not been included, we may, I think, fairly increase his estimate to say 6s. per ton. Taking the cost of railway freight at only $\frac{1}{3}$ d. per ton per mile—a cost which, under favourable conditions, is said to be realised in America—then $\frac{132}{3} = 44$ d. = 3s. 8d. per ton for railway dues, leaving 2s. 4d. per ton for getting, breaking, hand-picking, wheeling, loading, putting f.o.b. at Lulea, interest and superintendence, and 6d. per ton for royalty. A total cost price of 6s. 6d. per ton f.o.b. Lulea, is at all events not too high an estimate.

From Bilbao, which is 1030 miles from Middlesbrough, the present rate of sea-freight for conveyance of ore is about 5s. 3d. per ton. In view of the fact that Lulea is 1550 miles, or fully

* Report by J. Timmis Smith, issued by Sheppards & Co., 57 Old Broad Street, E.C., October 1888.

1½ times as far, and that, on account of ice, the traffic has to be done during five months only of the year, I think that an additional 1s. 3d., or a total of 6s. 6d. per ton, is not too high an estimate for the average freight from thence.* This brings the lowest cost price of Gellivara ore to 6s. 6d. + 6s. 6d., or 13s. per ton delivered in Cleveland, without reckoning any profit to producers.

Comparing this figure with 10s. per ton, which we have just found to be about as much as can at present be expected for grade C., it seems probable that grades A. and B., and perhaps D., will alone reach us in quantity, so long as Lulea, with its disadvantages of distance and seven months of ice, is the port of shipment. Certainly Germany and Austria are taking large quantities of grade D. in spite of all difficulties, but the protective tariffs of those countries enable the finished iron and steel they produce to be sold, in the home markets at all events, at prices which cannot be obtained by English makers, and those higher prices may justify the importation of relatively dear materials.

These conditions were by no means ignored by the original Swedish and Norwegian Railway Company. Their concession, which was first obtained in 1883, authorised them to continue their line through to Victoriahavn, on the Ofoten fiord. That fiord, and indeed the whole of the west coast of Norway, is always free from ice, however severe the winter. This is due to the fact that it lies in the path of the Gulf Stream, and of the warm winds which are continually moving from the tropics to the polar regions.

On the way to Victoriahavn, and 115 miles from it, or nearly the same distance as Gellivara is from Lulea, the projected railway passes the deposits of Kirunavara and Luossavara. These are similar in character to those at Gellivara (see Plate V.), and, though not quite so extensive, they are estimated to contain together enough for all probable demands for two generations at least. The similar deposit of Svappavara (see Plate V.) also contains a considerable quantity of ore; but being off the rail-

* The present actual rate of freight for ore from Lulea to Middlesbrough is 6s. per ton, but its continuance on so low a scale is very doubtful.

way route (see Plate IV.), need not now be taken into account, except as a reserve. (For analyses, see Table II. columns 3, 4, and 5.)

Owing to the early collapse of the English company, the railway was never carried through to Victoriahavn. The advisability of completing it is still under contemplation by the Swedish Government; but, as in the case of our own Channel Tunnel, military apprehensiveness has, so far, overridden commercial considerations. Should it be successfully accomplished, then clearly Gellivara will be left to supply Baltic ports when not frozen up, and Kirunavara and Luossavara, being nearer to the Atlantic seaboard, will be brought into action to supply English and other North Sea ports *via* Victoriahavn.

Middlesbrough is only 1170 miles from that port, whereas it is 1550 miles from Lulea. Rotterdam is 1323 miles from Victoriahavn, against 1550 from Lulea. Antwerp is 1400 and 1628 miles respectively. Stettin is considerably nearer to Lulea.

Relatively to Germany and Austria, England, and especially the Cleveland district, will secure the greatest advantage by the opening out of the Victoriahavn route. The average sea-freight is, however, scarcely likely to be reduced more than 1s. per ton, or from 6s. 6d. per ton from Lulea to 5s. 6d. per ton from Victoriahavn.

There is, therefore, little prospect of Swedish ore of any kind being delivered to Middlesbrough, even *via* Victoriahavn, at less than 13s. minus 1s., or say 12s. per ton; and this, as we have seen, is a higher price than can be expected at present for any kind except grades A. and B., and perhaps D.

In this minimum cost price of 12s. per ton, delivered at Middlesbrough, I have included 3s. 2d. per ton for railway carriage for the 115 miles from Kirunavara to Victoriahavn. It is obvious that if this item could be saved by the discovery of iron ore deposits, similar to those on the route of the Swedish-Norwegian Railway, but situated on or near the always accessible Norwegian fiords, such a discovery might bring down the cost price to 12s. minus 3s. 2d., or say 8s. 10d. per ton at Middlesbrough. Again, if such deposits were situated farther south than Victoriahavn, the freight also might be lower in proportion. Indeed, a cost price

of 8s. per ton delivered might, under such circumstances, be easily arrived at.

The careful and elaborate surveys of the Gellivara and the three neighbouring deposits which were made in 1875 by a Commission of experts sent for the purpose by the Swedish Government seem to have established the following facts, viz. :—

1. That the ore is all more or less magnetic, the metallic iron contained being in the condition of protoxide, [peroxide, or magnetic oxide, or a combination of these oxides.

2. That it is found in lodes or veins, which, together with the bed rocks in which they lie, appear to have had an intrusive origin, and are usually more or less distorted.

3. That the lodes are associated with gneiss, quartz, felspar, granite, hornblende, and mica schist. Corundum, fluorspar, calc-spar, actinolite, adamantinite, asbestos, epidote, and garnets are also found in or about them.

4. That the phosphorus is in the form of apatite ($\text{Ca}_3\text{2PO}_4$), and can to a great extent be separated by hand-picking.

5. That ore sufficiently free from phosphorus for acid steel purposes is but a portion, say one-fifth, of the whole.

6. That the deposits generally protrude at the surface of the mountains, where they are easily distinguishable from a considerable distance by their dark colour. The ore in sight, or traceable by the dip-needle, constitutes usually about 5 per cent. of the total surface area of the deposits.

7. That the more elevated and more outlying portions of the deposits yield, as a rule, ore containing less iron and more impurities than the less elevated and more central portions; and that samples taken from the interior of the lodes give better analyses than those taken from near the surface.

On this point Herr Gumælius of the Royal Swedish Geological Bureau, and a member of the Exploratory Commission, says, with respect to Gellivara: "The principal part of the ore, lying in the middle of the deposit, may be considered free from phosphorus, and this rather at its present depth than nearer the surface." Again, when referring to Kirunavara, he says: "The highest peak shows most phosphorus. From the middle peaks the percentage decreases on both sides steadily till one gets ores almost pure. We

are fairly entitled to presume that the percentage of phosphorus decreases with the depth. But one is not justified in drawing definite conclusions on this point without actual quarrying."

Herr Dellvik, of the Royal Swedish Iron Board, another member of the Commission, says of Gellivara: "At one place where there is a shaft 18 feet deep, the samples taken from the top contained 0.374 per cent. of phosphorus, and those drawn from the bottom only 0.031 per cent. This interesting result leads to the opinion that apatite may everywhere diminish with depth of working."

Of Kirunavara the same authority says that "he believes the whole mountain was at one time of uniform height; but that the lower peaks have suffered from denudation, and that the ores taken from them represent the quality which is likely to be found at the same level in the higher peaks. Consequently the phosphorus will decrease with the depth explored."

Let me now remind you of my remark, that if any considerable deposits similar to those we have been considering should be found on the west coast of Norway, such a discovery might have a still more important influence on the future of the iron and steel trades, especially those of Cleveland. For such ores, emanating from those always accessible fiords, should not cost more than 8s. per ton (exclusive of profit) delivered at Middlesbrough. They would be able to compete advantageously not only with Spanish ores, as the ores of Gellivara are already doing, but very probably also with native Cleveland ores in the manufacture of basic and also ordinary Cleveland pig iron.

But are there any such deposits on or near the Norwegian fiords? That is a question which I do not think any one can conclusively answer at present. Many deposits are known to exist, and some of them are of great extent. But no definite and systematic search has, so far as I know, ever been made. In various places where protruding ore has been found, concessions have been granted. But the native concessionaires generally lack the means to develop, or even to prove their properties. Unlike the Swedes, they are anxious enough for Englishmen to come with capital and skill to buy and work their concessions. But the enterprising capitalist naturally demands that the value of a mining property shall be proved to his satisfaction before he sinks

good money in its acquisition. This the native concessionaire usually cannot do for want of funds; and so the mining wealth of Norway, with its unusual advantages of position, remains to this day, to a great extent, undetermined and almost entirely unutilised.

In the summer of 1891 I visited several magnetic iron ore deposits in the neighbourhood of Grimstad and Arendal, on the south coast of Norway. The ore seemed to lie in nearly vertical lodes or veins of very variable thickness. In former times, several of them had been extensively worked, as testified by the pits, headings, heaps of bed rock and ore, and even remains of winding apparatus still to be seen. Many of these deposits have been partially or entirely exhausted, and are now full of water; and I found it difficult to obtain even samples of ore *in situ*. Other deposits of similar character had not yet been worked at all, and were traceable only by occasional holes and by the indications of the dip-needle.

The samples of ore I collected yielded the following results on analysis:—

Iron	from	38.2 to 64.9 per cent.
Phosphorus	„	traces to 0.214 per cent.
Silica	„	4.7 to 22.4 per cent.

(See Table II. columns 8 to 12.)

A considerable sum of money would have been required to develop those deposits which still contain ore, and to construct the necessary tramways and wharves. The quantity obtainable and the rate of output would scarcely have been sufficient to justify such expenditure, and my clients decided, on my advice, not to proceed further.

Near Soggendal, between Christiansand and Stavanger, is the titaniferous iron ore deposit formerly worked by the Titanic Iron Company, Limited, but now inoperative. It is a mile and a half long and 60 to 70 yards thick (see Table II. column 13). There is a similar deposit near Ekersund, 3 miles long and 2 to 12 yards thick.

To the north of Trondhjem is a vein of magnetite 11 yards thick and of unknown length. The specimen on the table marked Trondhjem W. is from this deposit. I regret that I am unable to give an analysis.

In June 1893 I again visited the west coast of Norway, passing from Bergen to the Lofoten Islands and back to Stavanger. I explored one mountain situated alongside of a deep-water fiord somewhat further to the north of Trondhjem, in which magnetite ore was protruding at various points, and which I estimated to contain not less than 25 millions of tons, or enough for an extensive export trade for a couple of generations at least. Specimens of the ore, marked Trondhjem X, will be found on the table, and also two analyses (see Table II. columns 14 and 15). These are not equal to what are obtained from Gellivara; but the only attempt at proving the deposit which has yet been made is a single pit about 6 feet deep. From the bottom of this the best specimen was taken, and the best analysis obtained. The other analysis is of samples taken from at or near the surface.†

This deposit has, so far as can be seen, all the outward characteristics of that of Gellivara. Its position is everything which could be desired for cheap working and exporting, and if sufficient enterprise and means were forthcoming to prove it thoroughly, it might come to fulfil very sanguine expectations. Several photographs, taken when visiting the locality last June, are on the table.

Not far from this deposit is another of similar character, which I call Trondhjem Y. It is 16 miles long by 44 yards broad. Its depth is unknown. One end of the deposit is within 12 miles of a small seaport situated at the head of a fiord.

Samples taken from near the surface yielded the analyses shown in Table II. column 16. The bed rocks are igneous and metamorphic, and generally similar to those of the Swedish deposits.

Still farther to the north are other deposits of magnetic and specular ore, which I call Trondhjem Z. Specimens taken from them yielded 64 per cent. of iron, 0.02 to 0.09 of phosphorus, and 0.01 to 0.3 of sulphur (see Table II. column 17).

In one of the Lofoten Islands I examined several detached deposits. The specimens I selected yielded on analysis 61 per cent. of iron and only traces of phosphorus; but they contained

* *Journal of the Iron and Steel Institute*, 1891, No. I. p. 254.

† The deposit referred to as Trondhjem X. is that near the farm of Fuglestrand, on the western bank of Elvsfjord, a branch of Ranenfjord, a little to the south of the Arctic circle. It is nearly the same latitude as Gellivara, and only about 200 miles distant from it in a direct line.

no less than 9·2 per cent. of titanitic acid (see Table II. column 18). The deposits do not appear ever to have been worked, although within a quarter of a mile of a good navigable fiord.

It will be noticed that titanitic acid is a very common constituent of Scandinavian ores, and in very variable proportions. Consequently its influence in the blast-furnace is a matter of considerable importance if these ores are likely to be increasingly used. The views of Herr Dellvik on the subject will no doubt be of interest. He says: * "As regards the percentage of titanitic acid in an ore, it is as yet a moot point whether it ought to be considered a good or a bad element. It is certain that it does not communicate any impurity to the pig: on the other hand, it may be contended that although the titanium in the ore does not with smelting enter into the pig, but remains in the slag in an oxidised condition, it yet communicates to the iron an unusual degree of toughness, and causes sulphur, and possibly phosphorus also, to go into the slag. That which may be charged against the titanitic acid is that it causes an increase of coal consumption in the furnaces."

Scandinavian magnetite ores if used alone have usually been found extremely difficult to smelt, and this has been supposed to be due to the influence of the titanitic acid contained in them. But if, as Mr. C. Wood has pointed out, they be smelted, not alone, but in combination with other and poorer ores, especially such as contain alumina, this refractoriness seems entirely to disappear. Certainly Messrs. Kupelwieser, Whitwell, and Walter Wood agree that they have met with no difficulty of that nature.

This will be a matter of no small importance should Scandinavian ores come to be purchased at a cheap rate, and used in Cleveland in combination with native ironstone for the manufacturing of basic and ordinary pig iron.

In the course of the discussion on the paper by Mr. Kupelwieser read at Darlington, I called attention † to Sweden and Norway as possessing almost unlimited supplies of iron ore, and to the fact that these might prove of the utmost service to the iron and steel industry generally, and especially that of Great Britain, which is so well situated for importing them. My revered friend Sir

* See *Iron*, January 14 and 21, 1887.

† *Journal of the Iron and Steel Institute*, 1893, No. II. p. 15.

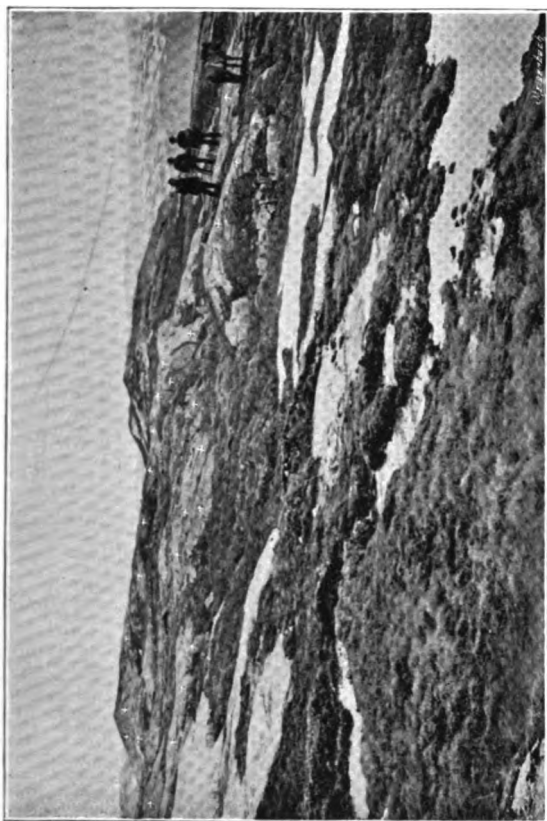
Lowthian Bell, who, I think, must have had in his mind the central and southern mining districts of Sweden only, then dissented from what he termed my "sanguine hopes." I trust I have now succeeded in convincing him and you that the question is not one of hopes only, but also of accomplished facts—facts of great significance, and which we certainly cannot afford to ignore.

I think also that we who are interested in the British iron, steel, and engineering trades ought to keep in our minds, more than we are accustomed to do, the precarious position we have placed ourselves in by depending so exclusively on one foreign country for steel-making ores. Twenty-five years ago, our ships, bridges, boilers, and railway-tracks were made of iron derived almost entirely from British ores. Now almost all these are made of steel derived from Spanish ores. What will happen if the Spanish Government lays a heavy export tax upon ore, or if the trade with that country be impeded by war, or even rumours of war, or by the exhaustion of the Bilbao deposits, is not pleasant to think of. At all events, we should be in an infinitely more sound and safe position if we had another string to our bow, in the way of a well-established traffic in ores adapted for basic as well as for acid processes, with our friends and kinsmen the Norsemen of Scandinavia.

In conclusion, I desire to acknowledge the obligation I feel under to various gentlemen who have given me valuable assistance and information for the purposes of this paper. Among them are Messrs. C. E. Müller & Co., of Middlesbrough; Mr. Paul Kupelwieser, of Vienna; Mr. J. W. Pearse, of Mondorf; Mr. Jarvis, C.E., of Westminster; Mr. William Whitwell, of Thornaby; Mr. Walter Wood, of Middlesbrough; Mr. William Barrett, of Brentwood; Mr. E. Waterhouse, of London; Messrs. Armstrong, Addison & Co., of Sunderland; Mr. W. Hawdon, of Middlesbrough; and my son and partner, Mr. A. P. Head.

PLATE IX.

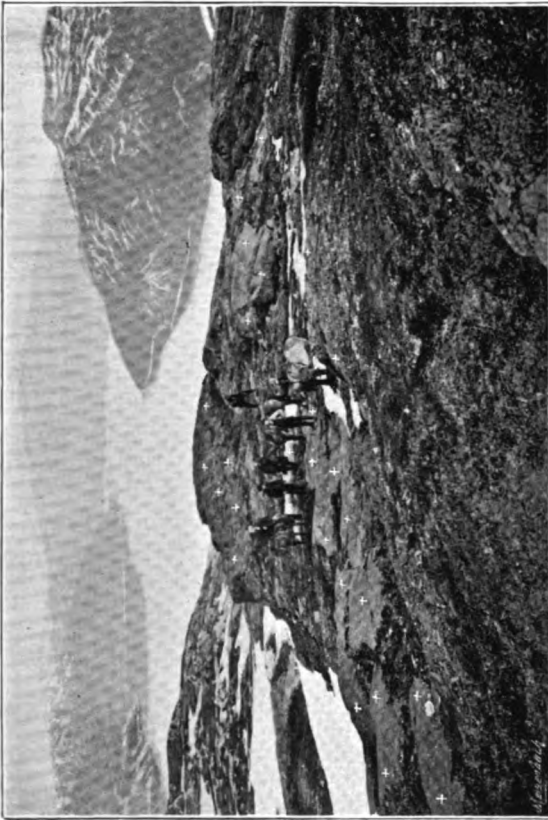
THE MAGNETITE DEPOSIT OF FUGLESTRAND, NORWAY
("TRONDHJEM X.").



The protrusions of Magnetite are marked by White Crosses.
Elevation 2150 ft. Direction E.

PLATE X.

THE MAGNETITE DEPOSIT OF FUGLESTRAND, NORWAY
("TRONDHJEM X.").



The protrusions of Magnetite are marked by White Crosses.
Elevation 2150 ft. Direction E.N.E.

TABLE I.—*Scandinavian Iron Ore Exports from 1870 to 1893.*

During the Year	To Great Britain.		To All Countries.
	1. From Sweden.	2. From Norway.	3. From Sweden.
	Tons.	Tons.	Tons.
1870 . . . . .	...	...	9,485
1871 . . . . .	...	...	13,132
1872 . . . . .	...	...	11,908
1873 . . . . .	...	...	18,662
1874 . . . . .	...	...	23,883
1875 . . . . .	...	...	27,210
1876 . . . . .	...	...	14,920
1877 . . . . .	...	...	12,491
1878 . . . . .	...	...	13,534
1879 . . . . .	...	...	12,570
1880 . . . . .	...	...	29,670
1881 . . . . .	...	...	24,932
1882 . . . . .	...	...	20,200
1883 . . . . .	...	...	32,319
1884 . . . . .	...	...	40,000
1885	613	2,410	25,819
1886	743	804	17,288
1887	657	2,485	41,765
1888	62,672	720	117,530
1889	15,427	135	118,571
1890	5,534	105	187,332
1891	3,108	305	174,148
1892	13,722	31	320,871
1893	35,601	...	447,931

TABLE II.—*Scandinavian Iron Ore Deposits.*

Country	SWEDEN.						UNITED KINGDOM.
	Gällivara.		Kiruna- vára.	Luossavara.	Svappavara.	Grängsberg.	
	Grade A.	Grade D.					
Column	1.	2.	3.	4.	5.	6.	7.
Metallic iron (Fe)	69.51	65.0	61.5 to 72.5	68.25 to 71.5	50 to 73	60.5 to 67.4	52.0
Manganese (Mn)	0.072	0.108	...	...	...	...	...
Lime (CaO)	0.202	3.688	...	...	...	...	...
Magnesia (MgO)	0.679	0.924	...	...	...	...	...
Phosphorus (P.)	0.01	1.353	0.03 to 2.8	0.01 to 0.08	0.129 to 1.547	0.54 to 0.98	3.25
Sulphur (S.)	0.088	0.088	0.03 to 0.15	0.03 to 0.09	nil.	trace to 0.73	1.0
Titanic acid (TiO ₂)	0.63	0.25	...	...	...	...	...
Silica (SiO ₂)	1.9	2.050	...	...	...	...	17.0
Alumina (Al ₂ O ₃)	0.25	0.065	...	...	...	...	...
Water (H ₂ O)	0.14	...	...	...	...	...	...
Analyst	Pattinson & Stead	Pattinson & Stead	...	...	...	...	...
Where obtained	C. E. Muller & Co.	C. E. Muller & Co.	Holland	Holland	Holland	<i>Stahl u. Eisen</i> , vol. xii. p. 9.	W. Hawdon

TABLE II.—(continued).

NORWAY.												
Country	Arendal.				Grimstad, Olstad Group.	Sogndal, Tittand-ferous.	Tromhjem X.		Tromhjem Y.	Tromhjem Z.	Lofoten Isles, Tittand-ferous Ore.	
	Tingstvedt and Lærestvedt.	Næse Killen, and Throm Island.	Braastadt (Kallevig), Faevik.	Cargo from			Taken from depth of 6 ft.	Taken from at or near surface.				
Column	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.	
Metallic iron (Fe) .	38.2	58.6	64.9	44.2	50.7	50.47	57.9*	46.1	42.38 to 58.94	64.3	61.1	
Manganese (Mn) .	...	...	...	...	...	0.42	0.19	2.184	...	...	0.28
Lime (CaO) .	...	...	...	...	...	1.06	1.80	1.747	...	...	0.99
Magnesia (MgO) .	...	...	...	...	...	2.16	0.32	0.26	0.125 to 0.35	0.02 to 0.09	traces
Phosphorus (P.) .	0.0173	0.0048	trace	0.214	0.0325	trace	0.082	0.013	...	0.01 to 0.03	0.011	
Sulphur (S.) . . .	...	...	...	...	...	0.02	0.016	0.013	...	...	9.20
Titanic acid (TiO ₂) .	...	...	...	...	...	17.4	0.1	0.62	14.6 to 32.0	...	2.35
Silica (SiO ₂) . . .	22.4	8.1	4.7	16.72	15.9	0.05	12.0	22.25	...	...	...
Alumina (Al ₂ O ₃) .	...	...	...	...	...	0.35	...	...	...	...	...
Water (H ₂ O) . . .	...	...	...	W. Whitwell & Co.	Pattinson & Stead	...	...	Pattinson & Stead	...	...	Pattinson & Stead
Analyst	Pattinson & Stead Author	Pattinson & Stead Author	Pattinson & Stead Author	W. Whitwell & Co.	Pattinson & Stead Author	W. Barrett	...	...	Haslebohm	...	Author
Where obtained .	...	...	...	W. Whitwell & Co.	Pattinson & Stead Author	W. Barrett	...	...	...	...	...

* Also 54.0, 57.0, 64.0.

DISCUSSION.

Sir LOWTHIAN BELL, Bart., Past-President, said his friend Mr. Head had done him the honour of alluding to him in the paper, from which it appeared that he spoke on a former occasion of the description of the resources of Sweden as an iron ore-producing country as being "sanguine hopes." At that time Mr. Head did not enter so fully as he had now done on the ground on which he based those hopes, whether sanguine or otherwise. He had now given them the ground on which he had formed the hopes of which he had spoken, and he (Sir Lowthian) must confess at once that instead of his apprehensions having been allayed by what Mr. Head told them they had only been confirmed. It was, he supposed, getting on for twenty years ago that he visited Sweden in order to examine the resources of that country as an iron-producing one. His explorations were no doubt confined, as Mr. Head had said, to the southern portion of the kingdom of Sweden. He believed the furthest north to which he went was the famous mine of Dannemora; but he happened to meet with gentlemen who were acquainted with what was proposed to be done at Gellivara, and he learned that there an enormous deposit of ore, specimens of which he saw at the time, resembling those produced, had been found at that particular mine, and that it was proposed to make a railway something like 120 miles long to a district which, it was true, for five months in the year had perpetual day, but, unfortunately for the district, during the other seven months of the year, they had perpetual night, and not only perpetual night, but perpetual winter.

It had been stated by Mr. Head that iron ore was conveyed in America at 0·3 of a penny per ton per mile, and from that it was attempted to draw an analogy between the position of this great mine in Sweden and the position of those of the United States. But he seemed to forget entirely that upon the American railways, which did the work so cheaply—and, he might mention at the same time, very frequently at a loss to themselves

—they had a perpetual traffic, summer and winter, and not only in one direction, but in both directions. How could one expect to compete with such operations as those in a country where the railway was for seven months in the year entirely laid idle, and of course all the capital with it. Then they were told of the distances that the ore was brought from the American lakes to the iron-making centres. No doubt it was a great distance,—not so far away, as Mr. Head admitted, as ore which had to be brought from Gellivara to this country. But he had omitted from his calculation that a thousand miles of that transport was done by water, and at a price that no railway could possibly compete with. Then they were threatened with a dearth of phosphorus, and it was proposed to have recourse to Scandinavia in order to make up this quantity of phosphorus that they were now able to derive from the puddler's tap, the stock of which was nearly exhausted, and no doubt as steel took the place of iron would get rarer and dearer every year; but the hills at Cleveland did not present such a doleful picture. They had ore there for hundreds of years, he might say, and the fault they had hitherto to find with the Cleveland ore had been its excess of phosphorus.

Fortunately, however, the difficulties encountered in making steel from Cleveland ores had disappeared, and now by means of the basic process they could grapple with them. But, at all events, as they had phosphorus so near at hand in Cleveland, surely they were not going to run away to Sweden in order to bring ore, certainly, 1500 miles, and of that 150 miles over a railway which would work under the most disadvantageous circumstances, to which he had just alluded. Quotations had been given from letters from people who had used this ore at Witkowitz and elsewhere. The Empires of Germany and Austria were so large that what might be practicable and even lucrative in one district was not so in another. There were districts in Germany which would compete almost with themselves in the manufacture of cheap iron, but Witkowitz and Silesia lay at such a distance from the Rhenish provinces, that they could afford to import ore there at a very much higher price than could be afforded on the Rhine. What was the prospect of bringing ore like this to the Rhine from such a distance, when they could now get ore in any

quantity from Luxemburg, and richer ore than Cleveland? That ore could be put into waggons at 2s. 6d. a ton, including every charge, and bringing ore from Sweden on account of its phosphorus to the works on the Rhine, was, as a permanent trade, not to be dreamt of.

Mr. EDWARD RILEY said he had spent a considerable time in Norway in investigating the ores there; all the way from Naes, mentioned in the paper, to Arendal, right up to Soggendal, Egarsund, Bergen, and a considerable distance above Bergen, to a place the name of which he did not remember. The quantity of the ore at Arendal and at Naes was very small indeed, just sufficient to supply the local furnaces which smelted charcoal iron. Exceedingly good charcoal iron was made, but the quantity was insignificant. At Soggendal there were splendid deposits of titaniferous iron. The quantity was unlimited, but the quality, on account of the high percentage of titanic acid, rendered the deposit practically useless for working. At that place the iron ore ran up the mountain in a mass 16 feet high, perfectly solid and metallic in appearance, and any one unacquainted with it would say from that appearance, what splendid ore it was. The fact was, there was any amount of titaniferous ore, but the titanic acid at present amounted to 45 per cent. A special feature of these titanic ores was that they did not contain phosphorus. Experiments with the ore were made at Norton, and he advised with regard to them. He said, "You can smelt paving-stones, but, in my opinion, you can never smelt titanic iron ore advantageously; you can smelt it at an enormous cost." It might be remembered that in Canada two furnaces were put up to smelt titanic iron ore with charcoal. What was the result? Very little was smelted, and the cost of the pig iron was £10 per ton. He had the analysis, and would admit that it was excellent pig iron, everything that could be desired, only it cost too much money.

That was the character of the ores he saw for some considerable distance above Bergen. He had been all over these deposits, and there was an unlimited quantity. There was an immense body of ore some little distance above Bergen, not so very highly

titanic; its average was about 15 per cent., and perhaps it was possible, though he hardly thought probable, before the basic process was adopted, that it might be used. There had been a very large amount of money lost in Norway in investigating these ores. Further north it was quite true that more magnetic iron ores were found, very rich, and in every way desirable, but the deposits he saw were too far from the seaport to make their use practicable. He did not say that there might not be iron up towards the northern part of Norway, but he had been up as far as Vefsen, a considerable way up, getting on towards the Lofoten Islands, and all the deposits of ore were titaniferous, and he thought all those who had experience of titaniferous ores would agree with him, that with their present knowledge, certainly since the adoption of the basic process, they were perfectly useless. He thought it possible that there were very large deposits of apatite in Norway. He knew at Krogerøe there was a large deposit of pure titanic acid (rutile) in apatite, and it was possible there might be found near the coast of Norway some iron ores mixed with phosphate of lime that probably might be used for the basic process. He thought that Norway had been pretty well explored. The Norwegians would come to you bringing little samples of iron ore, saying they had a mine to sell; so that he thought they would be more likely to spot any bed of iron ore than English visitors would be, and would have found out if there were any very great or desirable deposits for some considerable distance above Bergen.

MR. J. E. STEAD supposed that the author's statement that phosphorus in the form of apatite could be, to a great extent, separated by hand picking, referred to the ore containing apatite, but not to the apatite itself. As a matter of fact, it might be interesting to know that in all this ore the apatite was quite easily dissolved out by means of dilute acid. In determining phosphorus, it was very much better to dissolve the apatite out with very slightly acidulated water, as by that means they left the ore behind and got all the phosphorus in solution. If the ore was dissolved entirely, the titanic acid interfered with the determination of the phosphorus, and made it somewhat troublesome.

He might add that the ore containing apatite was very easily detected by the eye, and with a little education they could separate the bad from the good portions of the ore. The crystals of apatite were light coloured. Indeed, a cargo that came to Middlesbrough containing the two classes of ore was actually separated in the works into Bessemer and phosphoretted material by the labourers who, by half an hour's education, were instructed how to do the work, and it was done, he believed, perfectly satisfactorily.

Mr. WILLIAM WHITWELL, Vice-President, thought that the members of the Institute were very much indebted to Mr. Head for placing the facts so fully before them. What they as iron makers really wanted to know was, what were the real facts in connection not only with the present, but, so far as could be anticipated, for the future. Having had a good deal of experience of this ore, he would like to confirm everything that had fallen from Mr. Head with regard to its character, and he hoped the development—not only of existing mines but of further mining royalties—would prove that it was possible to continue to bring that description of ore to their English ports successfully, from a commercial point of view. He quite sympathised with Mr. Head in his speculative suggestion that hereafter they might not be satisfied to get the major part of the ore from Spain. But be that as it might, they had a certain element of quantity from Gellivara, though he confessed that the period during which it could be brought here at present was limited, and also the conditions seemed problematical as to whether they would be able to make a railway to Ofoten. It would be an exceedingly costly line to construct, and although the distance was only 120 miles, there would be a great deal of tunnelling, which would be infinitely more costly than the present railway made by the promoters of the old company. That, however, was a matter entirely for the engineer and capitalist, and he did not despair of seeing eventually that railway being made, because he thought there were those connected with Northern Europe who would be thankful to be able at all times of the year to have a port of exit to and from not only Norway and Sweden, but also Russia, and that was an element that would eventually have to be dealt with.

With regard to the facts, there was no doubt whatever as to the consumption of Gellivara ore in Germany. There was no doubt of nearly half a million tons of ore, mostly of the phosphoric type, going regularly to Germany and Austria. In spite of the nearer ores of Longwy, this ore was ordered and used very largely. Sir Lowthian Bell's personal friend, Mr. Krupp, was using it largely; and Mr. Holz, their old friend Mr. Kupelwieser's successor, was using it still more largely in Northern Austria. It was taken there at a very small cost by sea and lightered up to Breslau, within a very few miles of Witkowitz, so that the cost at Witkowitz was comparatively small in spite of the great distance. Quality would always tell, and this ore was not only excellent, but was richer than the ores of Lake Superior so fully alluded to by Mr. Head and by Sir Lowthian Bell. It bore carriage, therefore, better than the Lake Superior ore, on account of its greater metallic percentage. 69 per cent. was not at all an unusual average analysis of twenty consecutive cargoes of the best ores, and when it could be obtained pure it was admirable for pure hæmatite purposes. When not quite so pure, it must be used in a smaller quantity, and with comparatively pure ores from other districts. He did not, however, for one moment anticipate any very great development of pure ore delivered into England, because the proportions of the pure and impure were very different. The pure ore was in comparatively small quantities, and therefore they must not look for everybody to be greedy of obtaining their supplies from this source even if they desired it.

He did not think they could be sufficiently indebted to Mr. Head for going into the question as he had done. He had not only alluded to what existed, but he had told them of his further explorations on the north-west coast of Norway. He hoped those explorations might be continued, that those friends of his who were vitally interested in the development of the North Norwegian coast might carry out their investigations, because if ore could be found without the curse of titanitic acid, and of sufficient richness, at a certain reasonable price, there was no doubt it would be very advantageous in England to have two strings to their bow, and two sources from which they could get ore. He quite agreed

with Sir Lowthian Bell as to the phosphorus that was to be found in such plenitude in Cleveland being exceedingly useful, and likely to be increasingly useful, for iron and basic steel making purposes, but for best iron purposes they should look for other sources of supply than Spain, much as they were indebted to that prolific region. They could not think that the supply from Africa, as well as from Southern Europe and North Spain, could be regarded as likely to be seriously lessened for years to come. It would probably last their lifetime; but anticipating the future—for some of them had not very much longer to work at their individual trades—he thought the development of such sources of supply as Norway and Sweden might be looked forward to, without being too sanguine, on his own behalf and on behalf of those members who were especially interested in this paper, he felt exceedingly grateful to Mr. Head for the very clear and exact way in which he had placed matters before them, and he thought these were papers capable of being multiplied to almost any extent in the development of the great interest with which they all had so much sympathy.

The PRESIDENT said they were all agreed that this was a most carefully prepared paper, and must have cost the author a very great deal of trouble and care. There was one point, perhaps, at the end of the paper which every one would not quite agree with. The author there said it was not pleasant to think of "what will happen if the Spanish Government lays a heavy export-tax upon ore, or if the trade with that country be impeded by war, or even rumours of war, or by the exhaustion of the Bilbao deposits." He knew very many people in this country who would regard such a catastrophe with perfect equanimity.

Sir BERNHARD SAMUELSON, Bart., Past-President, asked if the author had any information with reference to the imports of Gellivara ore containing phosphorus into the Westphalian district in immediate contiguity with that obtained from Luxemburg. When at Amsterdam two years ago, he was told that the ironmasters of Westphalia consumed not only the pure Gellivara ore but also the ore which contained a large percentage of phosphorus,

and that they imported it for the purpose of being employed in the basic Bessemer converter. If Mr. Head had any definite information on that subject it would be extremely valuable.

MR. HEAD said he was extremely obliged to the members for the kind way in which they had received his paper. As mentioned by the President, it certainly had taken him a great deal of time and trouble to prepare. He had no "axe to grind" whatever, and no interest other than that which they should all feel in these matters, viz., a scientific interest. With regard to the criticisms offered, he did not think they had been in any way unfair, or beyond what he might naturally have anticipated. Referring to what Sir Lowthian Bell had said, he presumed that what he still dissented from was what he had termed his "sanguine hopes," and not his statistics derived from official sources, which proved that within the last few years the annual exports of iron ore from Scandinavia to this and other countries had increased by over 400,000 tons. He himself regarded this new development as marking an epoch in the iron and steel trades. As the exports were still increasing year by year, he thought they could scarcely afford to ignore them, still less to deny their existence. Sir Lowthian Bell was of opinion that the Gellivara mines and railway, and all the capital connected therewith, must be entirely laid idle for seven months in each year; because being situated on or about the Arctic Circle, they were in perpetual darkness, as well as winter for that period. A very little study of the elements of physical geography would be sufficient to satisfy any one that that view was quite incorrect. From places situated on the Arctic Circle, half the sun's disc was visible at noon on the 21st of December. On the 21st of March and 21st of September sunrise and sunset were at 6 A.M. and 6 P.M. respectively all over the world. The average duration of daylight during the six winter months was therefore the mean between twelve hours and nothing; or six hours. To this must be added the twilight which, in northern latitudes, was about one hour at each end of the day. Therefore instead of seven months of perpetual night, there was an average day of eight hours throughout the winter. Of course, during November, December, and

January the daylight was of brief duration, but he was informed by those who had spent the winter there that that was no inconvenience whatever. People were accustomed to work in the dark so far as it was dark. It was not, however, absolute darkness. The country was generally covered with snow; they had the aurora borealis, and the moon and stars shone with a brilliancy unknown in our damper climate. But the operations at Gellivara were not dependent on natural sources of light only. The mines were illuminated throughout with the electric light, and as a matter of fact, they and the railway went on just the same in winter as in summer. With regard to the rate of 0·3d. per ton per mile, he definitely ascertained, when in America two or three years since, that that was about the price charged in the case of mineral traffic in 25-ton waggons, and over long distances.

On the Gellivara-Lulea Railway these conditions equally applied. They had 25-ton waggons, a long run, and a descending gradient. At the shipping-place at Lulea they had two hydraulic lifts, each of which would raise two waggons containing 25 tons each. They therefore had all modern appliances, and were well situated for mining and shipping this ore very cheaply. The real impediment to continuous exportation did not arise from any difficulty in working or delivering the ore to a shipping port, but in getting it sent further on, so long as only a Baltic port was available. This was due to the fact that the Baltic was frozen up for seven months in the year. As he had explained at considerable length in his paper, this impediment would be entirely removed when the Victoriavägen route was opened out. He could not admit that he had made any error or oversight in comparing the distances and costs of ore transit as between Europe and America. There was railway and water carriage in both cases, and he had treated them separately throughout. He quite agreed with Mr. Riley that the Norwegian coast between Arendal and Bergen, and even as far as Trondhjem, did not contain any very promising iron ore deposits, and he had endeavoured to make that clear in his paper. The large deposits to which he had called attention were considerably to the north of Trondhjem. Mr. Riley had said that whatever high-class ore there was north of Bergen was situated too far inland to be of any use. He could assure him that

the one which he had called Trondhjem X in the paper was within a mile of a fjord (see p. 62), where a ship containing 4000 tons could enter, and lie safely afloat all the year round. Mr. Riley admitted he had only been as far north as Vefsen Fjord, and it was therefore clear he had not seen the largest and best deposits, which were still to the northward of that point. If he would be so good as to examine the photographs and specimens on the table, and the analyses of the latter, he would perhaps alter his opinion. Mr. Riley had also said that where there was titanitic acid there was no phosphorus. Of course Mr. Riley was a very great authority on matters connected with metallurgical chemistry, and he certainly did not like to contradict him; but if members would look at the analyses given in the paper, which were all fair analyses, and for the most part made by Messrs. Pattinson and Stead, it would be seen that that was not altogether the case. Mr. Stead had asked a question as to the apatite associated with the ore. The operation of grading by hand picking was, no doubt, confined to the rejection of those pieces which contained obviously a large proportion of apatite. The apatite in a particular lump could not be separated from the ore by any such crude methods. The different grades were, for the most part, obtained from different quarries. Of 131 quarries, there were some from which they were getting Grade A; in others they found Grade B, and so on. Sir Bernhard Samuelson had asked whether Gellivara ore of highly phosphoric quality was now being imported, *via* Rotterdam, into Westphalia in any quantity, notwithstanding the nearness of that district to Luxemburg. He believed that Krupps were getting some of Grade A; but the great majority of what was going to Westphalia, and all that was going to Silesia and Witkowitz, was Grade D for the basic processes.

The PRESIDENT proposed that the thanks of the Institute should be presented to Mr. Head for his valuable paper.

The resolution was carried by acclamation, and the meeting was then adjourned.

The proceedings were resumed on Thursday, May 3—Mr. E. WINDSOR RICHARDS, President, again occupying the chair.

The following paper was then read :—

ON THE CAPACITY AND FORM OF BLAST-FURNACES.

BY WILLIAM HAWDON.

THE aim, broadly stated, which the designer has in view in the construction of a blast-furnace, is general efficiency, which means economy, rapid production, and freedom from irregularity in working.

SIZE OF FURNACE.

First comes the question of capacity, the determination of which to a great extent depends upon the nature of the ore which has to be smelted and of the fuel used. Referring, however, to the Cleveland practice, we have seen that, within recent years, the capacity has been increased from about 6000 cubic feet to as much as 30,000, and there are very few furnaces now in blast which are less than 20,000. The increase, up to a certain point, has been attended with increased economy as well as larger output, and I believe it is the general impression that the largest furnace gives the best results—that is to say, that the fuel consumed per ton of iron is the smallest in the largest furnace, while the output is greater, although not in direct proportion to the increased capacity. This statement may be disputed by some, but I am not aware of any attempt to prove the contrary.

I propose shortly to consider somewhat in detail, and chiefly from a mechanical point of view, the effects at different stages of a blast-furnace which result from variety of form, referring also to the action of the materials when passing downwards through these stages, in relation to the chemical changes which are taking place.

THE WELL.

Let us first consider the well or crucible, the size of which is an important factor in the design of a furnace. This is determined by the most effective capacity of the melting zone, and the capa-

city is determined by the power of penetration of the blast. It is evident that unless the mass of material lying opposite and immediately above the tuyeres is open and readily penetrable by the blast, the combustion cannot proceed in a regular and equally diffused manner, but will be deferred until contact of air and fuel takes place. This may happen from two opposite causes—either from the well being too large in diameter or too small.

In the first case a pillar may be formed, and is probably often formed, of comparatively cold material in the centre of the mass, which the blast cannot properly reach on account of its compactness. It is clear that the existence of such a pillar must have a most damaging effect upon the working of the furnace, inasmuch as it is this part of the whole system which requires the greatest intensity and concentration of heat.

In the second case, although in the horizontal plane opposite the tuyeres the whole of the fuel may be brought into complete contact with the blast, yet the cubical contents at this part would be too small to admit of the requisite *volume* of combustion in order to obtain a given output over a given period. A portion of the blast would pass through this lower area, and in rising above it would have a cooling effect by mingling with incom-bustible material and the gaseous products of combustion, thus interfering with the diffused but at the same time intensified and concentrated heat which is so desirable in the immediate neighbourhood of the melting zone.

MELTING ZONE.

The capacity and form of the melting zone appears then to be also dependent upon the power we possess of so disposing the materials as to allow of an easy penetration of the blast, so as to obtain the most advantageous diffusion as well as concentration of heat. It is probable that the desirability of this concentration of heat at the melting-stage, which is of so much importance, has often been too much overlooked. It is not at all unlikely that it accounts in a great measure for the immense saving which at once sprung from the introduction of hot-blast by Neilson. For cold air blown into a furnace has to be expanded, which can only be

done by the expenditure of heat; but if the air is introduced at a high temperature, and already in an expanded state, we not only produce a more rapid combustion, but do it with a saving of fuel in the furnace.

It may be noted that, whether the blast is either cold or hot, the same number of heat units is developed with the same consumption of fuel, just as it is in an ordinary fireplace. But, to use a familiar illustration, we know that a kettle does not boil readily when the fire is burning low—it needs the bellows to blow it up and obtain the requisite temperature. In the case of cold-blast, intensity of combustion does not spread itself over a large space, and therefore a smaller well suffices. With blast of a high temperature we require a larger area at the tuyeres for economic working. I have dwelt on this question of cold-blast in order to emphasise the point which I wish to advance—namely, the necessity of the zone of fusion, having great intensity as well as capacity.

Having obtained this extended zone of high temperature, we have to utilise it, and this can only be done efficiently when the materials come down from the upper reaches of the furnace in a thoroughly heated and thoroughly reduced condition. They should also come down in as level and even a manner as possible over the entire area,—not with one part in a more forward state of preparation than another, otherwise the desired efficiency of working is lost.

I have endeavoured to lay before you, and laid much stress upon, the importance of the work done at this section of the furnace, because all the other stages lead to it. I am the more confirmed in my opinion as to the necessity of intense and amply diffused temperature at the zone of fusion from the fact that since the introduction of blast heated to say 1400° Fahr. obtained from brick regenerative stoves, experience has proved that furnaces with low boshes work more steadily and more effectually than with high boshes.

BOSHES.

This leads us to the bosh of the furnace, and in looking at the question, one is led first to consider why we want any bosh at all, and what is its function in the blast-furnace? In fact, it would

be well if we could do without it, for it is often a source of great trouble—the cause of more than half the evils which the blast-furnace is heir to. Still, so far as our knowledge of smelting extends, we cannot entirely dispense with it. We want it, first, in order to obtain capacity, and secondly, in order to support the material, and prevent too dense a packing near the tuyeres at the zone of fusion. As to capacity, the furnace must be large enough to contain ore and flux sufficient to abstract the heat from the ascending gases and get thoroughly reduced. The cubical capacity having been determined, the question arises, What is to be the height and what the diameter in order to work to the best advantage? Capacity alone, without reference to form, we know will not suffice—that is to say, large diameter with too small a height, or small diameter with too great a height, may both be objectionable. In the one case we do not get efficient lateral diffusion of the ascending gases; they find their course upwards by the readiest route, and leave a great part of the charge of ore unaffected by their action, and therefore in an imperfect state of reduction. In the other case, the height required to obtain sufficient capacity would be such as to crush the fuel by the weight of the column, and to pack the charge so tight as to obstruct the penetration of the blast.

The angle of repose, or of just commencing to move, for dry minerals, is 45° ; but being at this stage in a plastic and sticky condition, the angle of the bosh requires of necessity to be considerably more steep, from 68° to 80° being the limit usually selected, and approved by experience.

Having considered the well and its diameter, we have a starting-point for the bosh, and we carry up the angle until it cuts the line fixed for the maximum diameter of the barrel of the furnace; and it will be observed that the wider the well, the lower will the point of intersection be, while the narrower the barrel the more will it be again lowered. Under such conditions, it is clear that the materials will come readily down to the zone of fusion with little liability to stick at the bosh; whereas when the bosh occupies a larger vertical space of the furnace, retiring a long way back, we have the materials at the sides too far removed from the ascending current of gas,

and liable to come down if they come down at all) in a comparatively raw and cool state. I know of two cases which illustrate this last statement. After a few months' working, the furnaces happened to be blown out, and then it was discovered that some wooden sleepers, which were originally placed in to light up the furnace, in both cases had never been consumed, but were, in fact, only charred on the surface. They were found resting near the top of the bosh of the furnace.

In another case, a hole was drilled from the outside of the furnace to the top of the bosh, and part of the charge lying near the walls was abstracted, and this was found to be so cold as to be easily handled, although the furnace itself was at work. No stronger proof can be given than the above that in a wide furnace with a high bosh a great part of the ore lying round the sides is never submitted to the heating and reducing action of the ascending gases at all. It may lie there in the same position for months, and if it succeeds in coming down at all, it only comes down in a semi-raw state.

I am strongly of opinion, that in the Cleveland district there has been too great a tendency to build furnaces of large proportions, especially as regards diameter. The experience of comparative working seems to show that furnaces of smaller diameter have the advantage in regularity, and to a certain extent in economy. It is no doubt perfectly true that a certain amount of cubical capacity is always necessary, to give time for the absorption of heat and the proper reduction of the ores, and the larger the make which is proposed, the larger probably must be that capacity; and it is this consideration which has led to the construction of furnaces of such enormous capacity as 30,000 cubic feet; but it is no less certain that by increasing the diameter to an inordinate extent we run into the danger of incomplete reduction of that part of the ore which lies laterally out of the reach of the ascending current of gases.

It is difficult to fix upon the most advantageous diameter of the barrel of the furnace with anything like precision, but it appears to me that the smaller diameter and the shorter bosh meet all the difficulties better than those of larger and impracticable dimensions. Here we are driven somewhat into a dilemma, because in

trying to adopt a workable bosh of comparatively small diameter, which will carry out efficiently the functions I have already described, we are forced to raise the furnace in order to get capacity to a height which involves the risk of crushing the fuel and obstructing the blast by the mere weight of the column of material.

In order to obviate this difficulty, it occurred to Mr. Howson and myself that if the lower part of the furnace were made of comparatively narrow dimensions, the upper part might be enlarged in order to get capacity, because in the higher region the charge is in a dry and porous state, and not subject to that extreme pressure which obstructs the percolation and lateral diffusion of the gases, and, moreover, it is at this stage where *reduction* of the ore takes place in an economically working furnace; and further, the greater the area, the greater will be the bulk of ore acted on and reduced in a given time.

Having had practical experience of this form of furnace under varied experimental conditions for a considerable period, we are enabled to state that the objects in view have been attained in a very large measure.

Referring to Fig. 3, the full lines represent a diagram of this furnace. The dotted lines represent a diagram of a furnace as originally constructed, and which worked satisfactorily for nineteen years, and is a good type of the larger-sized Cleveland furnaces. It has been re-lined, and was replaced by lines of the smaller dimensions.

Before proceeding further, I would call attention to the fact, which Sir Lowthian Bell, Mr. Gruner, and others have before pointed out, as to the importance of carrying out the reduction of the ores at the upper part of the furnace; and I take the liberty of quoting Mr. Gruner, who puts it very concisely, when, in his "Studies of Blast-Furnace Phenomena," in alluding to large furnaces of about 30,000 cubic feet capacity, he points out that "if the work goes on *very slowly*, is not the CO_2 arising from the reduction of the ores exposed to be converted into CO by contact with *incandescent carbon*, in proportions increasing as the descent of the charges is slow?" And again, "It is important that the reduction of the ores should be effected by

CO being transformed into CO_2 , that is, without consumption of solid carbon." And this he calls an *ideally* perfect working furnace. "To realise," he says, "this, or at least to come as near to it as possible, the reduction must take place in a region of the furnace in which the temperature is relatively feeble, otherwise the CO_2 thus generated will constantly re-form CO at the expense of solid carbon. The furnace must be sufficiently capacious to ensure that the whole upper region should remain at this comparatively low temperature; but at the same time the ascent of the gases must be so rapid that it shall remain a very short time in contact with the solid carbon."

Mr. Gruner then quotes the proportion $\frac{\text{CO}^2}{\text{CO}}$ in the gases from two furnaces.

(1.)	{	0.3 of the total carbon under the form of CO^2 .				
	{	0.7	"	"	"	CO.
(2.)	{	0.2	"	"	"	CO^2 .
	{	0.8	"	"	"	CO.

The caloric given off—

$$(1.) \ 0.3 \text{ lb.} \times 8080 + 0.7 \text{ lb.} \times 2473 = 4155 \text{ calories.}$$

$$(2.) \ 0.2 \text{ lb.} \times 8080 + 0.8 \text{ lb.} \times 2473 = 3594 \quad "$$

$$\text{Difference } \frac{561}{\quad} \quad "$$

"Hence each lb. of carbon burned in the (1) furnace, must be replaced by $1 + \frac{561}{3594} = 1.156$, in the (2) furnace (equal to from 15 to 16 per cent.), by the single fact of a smaller production of CO_2 , or of the more energetic action which this CO_2 has for the solid carbon in the hot region of the furnace."

That is to say, if the good-working furnace uses 20 cwt. of coke, the bad-working furnace would use 23.1 cwt. coke.

The shoulder or upper bosh (see Fig. 3) sustains the weight of a large portion of the materials above it, thereby leaving that immediately below this point looser and more open, rendering the escape of the gases easy, and the working of the furnace more free throughout. In fact, it gives the benefit of the free working of a low furnace combined with the efficiency of a high one.

The cubical capacity of the larger furnace (Fig. 1) is 30,000 cubic feet; that of the smaller furnace (Fig. 2) is 24,000 cubic feet.

In laying before you a comparison of the actual work done by

furnaces built on the lines which we have been discussing, the figures have of necessity to be taken at periods some years apart, when the furnaces were new or the linings new; and we are not alone in our experience at the Newport Iron Works, where these results were obtained, when we find that now-a-days the percentage of fixed carbon (which alone is reckoned for duty) found in the coke is very much lower than it was some few years ago; and therefore I give, for the sake of comparison, the weight of fixed carbon consumed per ton of pig iron in its manufacture, and not the weight of coke. Taken over twelve consecutive weeks' working, the results obtained in the Howson and Hawdon form of furnace were as follows:—

Average Quality of Iron made over Twelve Weeks.	Average Make in Tons per Week.	Fixed Carbon Consumed per Ton of Iron made.	Calcined Ironstone used per Ton of Pig Iron made.	Temperature of Blast.
2·83	680	Cwts. 16·64	Cwts. 47·2	1400° F.

In examining these figures, I must point out that our aim was to make as much Nos. 1 and 3 iron as possible, in which it will be seen we were very successful, the weight of iron below these grades being only 16 per cent. of the total make. Were we to burden the furnace for 4 Foundry or Forge qualities, the consumption of coke would be probably further reduced by 1 to 1½ cwt. per ton.

Lime (burnt) was used during this trial instead of limestone, and it is somewhat remarkable that, though several times previously this had been tried on our furnaces at Newport, the result did not justify a continuance of its use; yet with this furnace there was a distinct saving of coke, probably over 1 cwt., which must be allowed for in the comparison. The results obtained with old lines when the furnace was new were as follows:—

Average Quality of Iron made.	Average Make in Tons per Week.	Fixed Carbon Consumed per Ton of Iron made.	Calcined Ironstone used per Ton of Iron made.	Temperature of Blast.
3·02	458	19·5	Cwt. 46·7	1260° F.

In examining these figures, it will at once be seen that the output is much increased, the fuel consumed materially decreased,

due partly to increased temperature of blast, though the weight of ironstone used is slightly increased, and what to a Cleveland manufacturer is of immense importance, the grade of iron produced is much higher, showing the very regular working obtained from the furnace; and I may here remark that so far as our experience goes this regular working is a marked feature in the duty obtained from this construction. Calculated in the same manner in the smelting of hæmatite in a furnace on these new lines, the consumption of fixed carbon is 15 cwt. per ton of iron made with a 50 per cent. ore, with a weekly make of 932 tons. I do not claim for the upper bosh the whole of the improvement effected in this furnace. I am of opinion that the somewhat large well, the low bosh, and the narrowing of the barrel above the bosh, claim a full share of it. It must be remembered that the lower bosh can only be properly obtained by adopting a barrel of more contracted capacity, the contraction being carried out in that part of the furnace where the ore has already come down in a more or less reduced state, inasmuch as the reduction has been amply secured in the upper enlarged region of the furnace.

It was in the course of our original trials that the position of the upper bosh was fixed rather too low, the consequence of which was that the materials were apt to pack and wedge themselves so as to form a dry scaffold when the furnace was filled. It was therefore found, after due experiments were made, advisable only to work the furnace filled some 20 to 22 feet above this upper bosh, and the results given below were obtained when the furnace was so working, leaving the capacity of the working part only 18,100 cubic feet. The furnace was further filled occasionally, so that the working capacity reached 21,000 cubic feet, and a marked saving of fuel was the result. But it could not be worked for long filled to this height, as the materials threatened to wedge, so that the lower capacity has been maintained. Availing ourselves of the experience gained from the first experiment, we have raised this upper bosh in our second furnace, so that it can now be filled to its full capacity, and it is working in a very satisfactory manner.

We think, then, that here we have a furnace which meets in a marked degree the conditions required for the successful treatment of ores in the blast-furnace, and which in practice gives very satisfactory results.

As regards the shape of the furnace at the bosh. Referring to diagrams Figs. 1 and 2, models were constructed, $\frac{1}{4}$ -inch to the foot, on the same lines (see Plate XIII.). They were filled with slag of a whitish colour, and afterwards charged with lime, limestone, and coke, in the order used in ordinary work, and the pieces broken to scale to suit the model. As the slag was withdrawn at the bottom, the charges were put in at the top, and the result was that when the charge had descended and filled the well of the furnace, as in Fig. 1, the large portion, shown by the dotted lines, and marked A, remained on the bosh of the furnace, showing how very slowly this part of the furnace does its work. But referring to Fig. 2, when the charge had descended to the well, the result was as shown by the dotted line enclosing the portion marked B, showing the advantage of a lower bosh and smaller diameter of furnace. And when we consider that the materials at this point are in a more or less melted condition, and would not rest on the bosh in the same way as the dry materials experimented on, we at once see that this area of materials at B will be diminished, if indeed it does not entirely disappear.

As showing that reduction of the ores is mainly obtained within a few feet of the top of the furnace, I had a $2\frac{1}{2}$ inch diameter wrought iron tube passed through a hole in the charging hopper. This tube had the end plugged with a spike, and holes were drilled about 4 inches from the bottom. The top end was also plugged up, and a small tap inserted near the top, from which samples of the gas were taken. This tube was thrust down into the materials in the furnace, and samples of gas taken at different depths. The following were the results, as determined by Mr. R. Williams at the Newport Laboratory:—

	CO ₂ .	CO.
	Per Cent.	Per Cent.
Gas as escaping from the top of the furnace	11.0	29.5
4 feet into charge	10.5	29.5
8 feet into charge	8.0	27.0
10 feet into charge	7.0	32.0
12 feet into charge	7.0	33.0
14 feet into charge	6.5	31.0

These results do not represent an average analysis of the gases taken over any long period, such as a day's working, but taken over some three-quarters of an hour, merely with a view to illustrate the reduction which is taking place at this zone of the furnace. They show that the ores are mainly reduced in the region of the top of the furnace, probably within 20 feet, and in that part where the furnace (Fig. 2) is enlarged to meet this requirement.

From the foregoing remarks it would thus appear that there are four principal considerations to take into account in designing a blast-furnace :—

1. Reduction of ore *near the top*, where the temperature *should be cool*.
2. Rapid descent of materials, after reduction, when *in the region of incandescent carbon*.
3. Capacity, in the horizontal plane, immediately in the zone of fusion.
4. Such a form of furnace as will keep the materials in a loose or open condition, and best contain the ores for the absorption of heat and reduction by the gases.

Whilst such considerations are necessary, it appears to me we have, in Fig. 3 dotted lines, a form of furnace which best meets the case.

For having disposed of consideration No. 3, and made the barrel small enough to meet No. 2, we enlarge the top of the furnace to twice the area of the barrel, in order to expand and cool the gases, and meet consideration No. 1. At the same time this upper bosh *turns over* the materials as they pass by it, exposing all parts of the surface of the ores to the ascending gases. And, finally, the contraction midway down the furnace greatly assists—if, indeed, it does not quite carry out—consideration No. 4.

DISCUSSION.

Sir LOWTHIAN BELL, Bart., remarked that Mr. Hawdon's paper was a very interesting contribution to the science of blast-furnace management. With the existing knowledge of the behaviour of furnaces in general, it was necessary to be content to wait a little to see whether the undoubted success which he had described as having attended his efforts was maintained over a longer period than that over which his observations had extended. Ironmasters in general could not fail to be grateful for such efforts, because in his own experience, and in that of every one, he believed, who had used superheated air, furnaces to which brick stoves were attached were much more prone to hang, as it was termed, than when air was heated in metal stoves, say to 900° or 1000° Fahr. In all blast-furnaces there were two conditions to consider—the mechanical descent of the materials and the chemical action of the operation, the latter being entirely dependent on the proper performance of the first. Following the order of the action in the different zones, he would observe, respecting the well of the furnace, that he doubted that in actual practice a solid pillar there was one of ordinary occurrence. Mr. Hawdon was quite right in saying that the actual heat evolved by the union of carbon with oxygen must be the same, whatever might be the temperature of the blast; but in dealing with the *quantity* of heat, it was necessary to add that contained in the air; and the result, therefore, was precisely the same, whether the view the author propounded be correct or not.

He was not sure that the author of the paper was correct in the opinion he enunciated about the nature of the combustion at the tuyeres in hot and cold blown furnaces. His own belief was that in both cases any carbonic acid generated was almost instantaneously reduced to carbonic oxide.

In one respect, in the proper function of what he called the melting zone, he was under a misapprehension. He (Sir Lowthian Bell) had explained in his paper read at Darlington somewhat fully

that "a thoroughly reduced condition" of the ore before it reached this zone never took place. On the contrary, 25 per cent. or more of the original quantity of oxygen was not separated from the iron until the well was reached. In his opinion, if all this oxygen were expelled in the zone of reduction—that was, in the uppermost zone—which he did not believe ever happened, the reduced metal would be reoxidised before it descended to the melting zone. This was, as he imagined, due to the dissociation of carbon monoxide, by which two equivalents of this gas were resolved into one equivalent of carbon dioxide, and one equivalent of carbon ($2\text{CO} = \text{CO}_2 + \text{C}$). At the same time a certain quantity of oxygen from a further as yet unknown quantity of carbon monoxide, combined with iron, or what amounted to the same thing in the furnace, was never separated from the metal.

Mr. Hawdon quoted him as an authority on the reduction being best carried out in the upper part of the furnace. As far as the nature of the process admitted, this was perfectly true; but in another place he mentioned that the complete reduction of the ore was impracticable, and in this opinion Mr. Gruner, also quoted by Mr. Hawdon, entirely agreed.

Some importance was attached in the paper to enlarging the upper part of the furnace, in order to increase the area of the reducing zone. He suspected this was entirely unnecessary, because observation led him to think that deoxidation of the iron peroxide was very rapid. In a furnace, say, of 20,000 cubic feet, it was permissible to give 8 feet as being occupied by the bell and cone. If so, no materials would approach the charging level nearer than 8 feet. In the next 8 feet or thereabouts the level of the surface of the ore, &c., would fluctuate as the charges were added. Now, he ascertained that within this distance all the oxygen capable of separation from the ore, and all the carbon dioxide of the limestone were expelled. This was further proved by the fact that at depths below the 16-feet level practically no increase of oxygen took place, and it was not until the well was reached that the remainder of the oxygen was found in the gases together with the carbon which had been separated by the dissociation of a certain quantity of carbon monoxide in the manner already mentioned.

These differences of opinion did not affect in any way the

value of Messrs. Howson and Hawdon's inventions. They merely amounted to a dissent from the mode of action in the furnace. If the enlargement of the zone, that was distinguished as one of reduction, obviated the inconvenience of hanging, those gentlemen would have done a good work, and one in which he wished them every success.

Mr. E. P. MARTIN, Vice-President, had followed Mr. Hawdon's paper with great interest. Generally speaking, the question of difficulty of hanging with high heats had necessitated the gradual bringing down of the boshes. He looked upon the enlargement of the hearth as having given great advantage in keeping the boshes at a proper angle. The greatest improvement that was likely to come from Mr. Hawdon's furnace was in the use of soft coke or coal. He (Mr. Martin) thought that in all probability the higher bosh would relieve the crushing that went on in the furnace, and to that extent would be a benefit.

Mr. CHARLES WOOD said he would like to ask Mr. Hawdon a few questions. He thought the members would agree that Mr. Hawdon and Mr. Howson had made a very bold and, he might say, grand stroke in the advancement of furnace-building. They had studied the working of the furnace, and he quite believed they had made a great success, if their statistics could be maintained. Whether that success was altogether due to the top bosh, he was not prepared to say. He would like a little further information and experience. Mr. Hawdon had said that he did not see the necessity for boshes. Well, if it was remembered that the blast, when it entered the hearth, was already expanded by the hot brick stoves about three times its volume, and that when it entered the hearth, and met a temperature of between 2500° and 3000° it would expand again about four or five times more. Meeting also the resistance of the materials, and the enormous volume of gas which was generated, unless a considerably increased area was obtained, there would be what he should call a journeying of the gases. He therefore looked upon it as an absolute necessity that there should be an increased area in order to relieve the pressure of that accumulation of

gases. He quite agreed with Mr. Hawdon that they had been led astray by the old-fashioned furnaces. In 1876, Mr. Pattinson* read a paper before the Institute upon the examination of the deposits on the boshes of the furnaces at the Tees Iron Works; and it was a remarkable thing that the inside of the furnace in question, when blown out, as nearly as possible represented the inside line of Mr. Hawdon's diagram of his new furnace. The lines of the furnace had been taken after blowing out, and measured every 2 feet down. But what was the composition of that material? The strange thing was, it was composed chiefly of silica, alumina, and potash. There was a white deposit against the brickwork, about 9 to 12 inches thick, of almost pure white, and the rest mixed with carbon, amounting to about 2 feet altogether, of which large quantities were analysed by Messrs. Pattinson and Stead, and the results, which were very interesting, had been published in the paper referred to. If the formation or collection of that deposit could be prevented, the regular work in the furnaces would be very greatly facilitated; because he believed that the collection and gradual formation of those deposits, and their coming down along with the burden continually into the hearth of the furnace, might be said to poison the quality of the iron and the gases, so that proper reduction did not take place. A furnace would work for a few days wonderfully well, but all at once it turned on to white iron. If that could be prevented by bringing the boshes down lower with a proportionally larger hearth, and with the boshes sufficiently large to allow for the expansion of the gases of which he had already spoken, and for the penetration of the gases up to the walls, he was quite sure a steadier and a better working furnace would be obtained. He thought that that was the point where Messrs. Hawdon and Howson were going to get their greatest success. He was not prepared to say that the top bosh was not a good thing at all; it might or might not be. And he did not pay much importance to the question of taking off the weight from the lower boshes. Mr. Hawdon had undoubtedly materially increased the size of the hearth, and that would also give a better opportunity for the gases to get up into the boshes. He had likewise increased his pressure

* *Journal of the Iron and Steel Institute*, 1876, No. I., p. 85.

of blast. He (Mr. Wood) thought that when Mr. Hawdon made the comparisons between the old and the new furnaces those matters ought to be taken into account. Another thing he might ask Mr. Hawdon was, after the return from the American meeting of the Institute, there was a great question mooted about isolating each furnace with a separate blast-engine. He was aware that Mr. Hawdon had tried some experiments, and those might also have had a bearing upon the better working of the new furnace. The author mentioned that he was going to work with $16\frac{3}{4}$ cwt. of fixed carbon, and he also mentioned that, if he made forge qualities, he would do with $1\frac{1}{2}$ cwt. less than that. Some years ago he (Mr. Wood) had heard that the neighbouring furnaces were going to work also with 17 and 18 cwt. of carbon, and he wondered whether those gentlemen were also neglecting the ash. He would like to ask the author what he meant by fixed carbon, because in his (Mr. Wood's) mind the question of fixed carbon had lately been one of immense importance. Coke coming from the beehive oven was in the form of large pieces of a silvery appearance, and if knocked gave a metallic sound. Coke coming out of some of the patent ovens was in blocks, dense, heavy, and black-looking. He had a very firm conviction in his own mind that, in the action of the burning of those cokes in the beehive oven, there was a very much higher temperature, and the coke was spread over a large floor, so that the gases, and pitch, and volatile carbon passed off readily into the atmosphere, or burnt as a little air was let in, and the coke arrived at a much higher temperature. Taking the coke made in the patent deep, narrow ovens, where the walls were kept at a red heat when the coal was charged into them, the walls, being red-hot, confined the tar and volatile carbon. The distillation of the coal went on very quickly, and the gases (which in the old beehive oven passed off) were largely retained in the coke. He was liable to error, but he thought that that was the reason why the yield of coke in those narrow ovens was so very much heavier than it was in the old-fashioned beehive oven. The tar and much of the volatile carbon were retained. It was certainly in the shape of fixed carbon when it came out of the oven, he admitted; and if that coke was given to an analyst, he would say there was not very much differ-

ence between one coke and another. He had proved over and over again that furnaces worked with 1 cwt. or $1\frac{1}{2}$ cwt. less of the beehive oven coke than with that fearfully dense, greasy, heavy coke. He would like to ask Mr. Hawdon where he drew his line of fixed carbon, if his (Mr. Wood's) arguments were correct. His point was, that a fixed percentage of carbon in coke was a fictitious one. There was no doubt that the beehive oven coke, with a larger percentage of ash, would carry a heavier burden and make better iron than the coke made from some of the patent ovens.

Mr. DAVID EVANS, Member of Council, had followed Mr. Hawdon's paper with great interest, and he thought that great credit was due to him for trying to improve the working of blast-furnaces. He agreed with Mr. Wood that there were certain explanations required with regard to the tables. He thought it would have been better if the author had given them the yield of coke in cwts., as, if they took the whole of the coke used in the Cleveland district, there was not much difference in the coke used by different firms; and therefore for comparison there was no need to go into the details of the fixed carbon. There were a great number of people who, by looking at the tables, would come to the conclusion that the actual consumption of coke was shown. He thought they ought to have more explanation of the comparison of the old and the new furnaces. What was the number of tuyeres, the pressure of blast, and the heating capacity? Had there been more stoves put down? Then there was the question of the consumption of lime as against limestone. He had lately found by experience that if the coal consumed to calcify the limestone were added, there was no benefit in it; and whether that was so, or whether Mr. Hawdon had taken that into account in calculating the yield of coke he was not aware. It was well known also that a new furnace would always work better than an old one, and therefore there should be some allowance for that. With regard to the make, he might say that at the works with which he was connected there was a furnace, similar in size to that described, making about 750 tons of Cleveland iron a week with $20\frac{1}{2}$ cwt. of coke, on the lines that were originally, he thought, designed by the President. It had been in about nine years, and was now making

750 tons a week with $20\frac{1}{2}$ cwt. of coke; and as regarded quality, over 75 per cent. of No. 3 for six months, the blast being $4\frac{1}{2}$. With reference to what Mr. Wood had said, he (Mr. Evans) disagreed with him entirely. He had had considerable experience in managing blast-furnaces and using different grades of coke, especially coke used in the beehive, and also by the patent ovens; and his experience was not in accord with Mr. Wood's statement that the coke was harder from the patent ovens than from the beehive. He might say that he had had six months' trial of two furnaces built exactly alike, one using patent coke, and the other using beehive coke, and it was found that there was very little difference; and if there was any difference, it was in favour of the patent coke.

Mr. WILLIAM ROBERTS would be glad to know what was the diameter of the furnace at the tuyeres; it was rather difficult to understand the proportions in the drawings. The number of tuyeres were not so important. With reference to the width and height of the bosh, he had known a furnace where old barrow sides or pieces of wood, put in when the furnace was blown in, had come out after eleven years. That was at Messrs. Hopkins', at Lipton, in Staffordshire, where the bosh had been too low, too wide, and too flat, and the blast, instead of going through the whole width of the furnace, had gone higher up, and had missed the circle of the furnace, where the bosh had been too flat and too wide. It was a rather singular circumstance. He thought the narrow furnace ensured the gases going through the whole of the materials, and preventing anything like hanging at the boshes, and lumps coming down, sticking at the tuyeres, and so damaging the quality of the iron. He had had the misfortune to work a Ferry furnace for ten years, which was built very high indeed, and very narrow; and the result was that the consumption of coke was small, but the iron made was bad. It was a very singular fact that in those ten years that the furnace worked there were not much more than 100 tons of white iron made; the result of the gases going up through the whole of the materials preventing any part being only partially acted upon by the gases. That showed it was very important the gases should go through the

whole of the material. He noticed the peculiar manner in which the patterns came down into the centre of the diagram, showing how the centre of the load gained on the outside; and he thought that taught the lesson, that if the upper and second bosh, which was shown in the diagram a third of the way down in the furnace, were at the very top—or, in other words, if the bell and cone were made very much larger—a similar working would take place, as was now shown by making this second bosh low down; in other words, if the full width of the furnace were taken advantage of, by having the top of the furnace as wide as the width of the whole furnace permitted, and having the bell and cone as wide as the width of the top of the furnace permitted, and the filling round the outside of this much increased top, then he thought that they would achieve the result with much less trouble and paraphernalia than they did by making this second bosh lower down. That was to say, that if the top of the furnace were 16, 18, or 20 feet, and the bell and cone, instead of being only 10 feet, were extended to the very utmost limit by which they could get the coke and minerals through the outside, they would achieve at the top of the furnace that which was achieved, according to the drawing, 20 feet down. It had been found in South Staffordshire, that if the bell and cone were made as large as possible, the same result was obtained as that which was obtained by the diagram. Reference to the diagram showed that there was a constant working of the load from the outside to the middle, and in that way larger materials were got in the centre, and those larger materials went down to the bottom, as had been said, and prevented the core in the centre, in which the blast did not enter. The result of coke yield in the new furnace was not, to his mind, a very considerable success. It was stated that $16\frac{1}{2}$ cwt. per ton of iron of pure carbon was used, which, with perhaps a tenth for impurities, brought the coke up to $18\frac{1}{2}$ cwt. per ton of iron, and was quite possibly a small consumption of coke. But in comparing the two, one trial with another, he observed that the heat was 1400° in one, and 1260° in the other. It would be much more satisfactory if those two heats were similar. If the new furnace were worked for a year or two, they would then know how far it was possible to maintain the lines; because it was quite certain that if they could

put a furnace in on certain lines, and make it continue on those lines, they would get as good a result with an old furnace as with a new. If the paper was re-written in five or ten years' time, there might be a consumption of coke recorded such as is used in the generality of furnaces in Cleveland and other parts of England. He hoped that experiments more completely comparing the heat of one furnace with that of the other would be made, and then another discussion on the subject arranged. One saw at Dowlais, where the tuyeres were large and the make of iron immense, three or four courses of water-pipes inside the brickwork of the furnace, to try and make it retain its original shape; and he thought it would be almost impossible for the new furnace before them to retain the shape it now had. He would ask what was the size of the "hearth" where the tuyeres were blowing?

Mr. ILLTYD WILLIAMS was not at all certain how much of the economy of the furnace was due to the lower boshes, and he thought it would be a very valuable experiment if Sir Bernhard Samuelson & Co. would build a furnace alongside of the other, continuing the lines from the lower bosh up to the top, and not bending them out to form the wider top. He had had some slight experience of working a furnace that was wider at the top than it was at the bosh, for the reason that the furnace lining fell in at the top. Under these conditions, the section of the furnace was something like that shown in the diagram; but the result was not at all satisfactory in the way of economy; and he thought Mr. Hawdon would find practically as much economy if he carried the lines straight up to the hopper.

The PRESIDENT remembered that on the occasion of the American meeting of the Institute, he met Mr. W. J. Taylor, who described a blast-furnace which had no bosh,* and it was certainly a source of great amusement. Mr. Taylor said there was no bosh—or furnace—after a very short time! If there happened to be an American manager at the meeting, he would be very glad if he would tell them about that furnace.

* *Journal of the Iron and Steel Institute*, 1884, p. 702; 1885, p. 713.

Mr. WILLIAM EVANS (Cyfarthfa) had not had time to consider the paper, but it seemed to him that, in discussing the internal lines of a furnace, it was necessary to take into account to a very large extent the class of material dealt with. The lines that might suit admirably in one district were unquestionably such as would not suit under different conditions in another district; and that being the case, he did not think they could arrive at specific lines that were going to be universally successful. Looking at the diagrams, he could see that the capacity was very materially reduced, and in consideration for that reduction of capacity it was supposed that the point of fusion was carried considerably higher up, and thereby an economy in fuel was effected. He very much questioned whether it was going to be what Mr. Hawdon had actually represented. He was of the same opinion as Mr. Williams, that if that furnace was made parallel from the bottom bosh to nearly the top, the effect would be practically the same as without the wide part at the top. He had had experience with narrow furnaces at Cyfarthfa, practically following the Treforest lines. He regretted to say the boshes were rather high, and that whilst the furnaces at Cyfarthfa worked tolerably well as regarded consumption of coke, they frequently had a difficulty with hanging; and that difficulty, to his mind, was due to the high boshes. If the boshes had been lower, nearer the part where the temperature was greatest, the hanging would not last as long, because the heat within a short distance of the tuyeres, where the temperature is high, would have been the means of fusing, and thereby bringing down the obstruction sooner. There was one furnace that hung for about nine days, and to get over that he had to drill holes high (he guessed where the mischief was located in the furnace), and he put a tuyere there, and brought it down in from four to five hours; and he had to repeat that instance at Cyfarthfa, due to his mind to the high boshes. He recently lowered the boshes and kept the furnaces narrow, and he believed, with regard to economy in coke, that it was not perhaps quite so much the capacity that they were indebted to for that economy as the height of the furnace, and adapting the position of the bosh to suit the material that had to be dealt with. Of course there were other circumstances in connection with the working of blast-furnaces which had to be

considered in deciding on the lines—the temperature of blast, the pressure of blast, and several other points.

MR. J. E. STEAD said Mr. Hawdon had been good enough to allow him to examine the books recording the working of his furnaces last week. He (Mr. Stead) had done this, and so far as the working of the furnaces was concerned at the present time, he thought his observations confirmed what Mr. Hawdon had stated in his paper as regards the actual results being obtained. The quality of the iron was wonderfully regular, and the furnaces seemed to be working also very regularly, and the books indicated a comparatively small consumption of coke. But when it came to a question of trying to find out the cause of the increased output and the reduced consumption of coke, there were four questions which at once arose. First of all, Mr. Hawdon had increased the size of his well; he had narrowed the diameter of shaft of the furnace; then he had flattened his bosh; and he had also made the upper part of the furnace much wider than the lower part. Theoretically, ever since he (Mr. Stead) first saw the lines of a blast-furnace, it had struck him that the right thing would be to have a furnace really very low with a very wide top, provided, of course, Nature would allow it; that was, if they could get the gas ascending from the lower shaft of the furnace to permeate regularly through the upper part. As they all know, all gases or fluids, or any kind of liquid, had a tendency to pass, and would pass, along the line of least resistance, and if a furnace were made unduly large at the top, and all the rubble or "lumpy" material fell into the centre, the line of least resistance would be right through the centre of that furnace, and the outside would simply act as a hopper to supply material to the narrower part below. It was therefore a question as to how far it was possible really to enlarge the top of the furnace, so that the gases would pass and fill that upper part completely, and effect reduction over the whole of the area. He thought it might be said that the reduction in temperature and the accompanying chemical action was effected when a given volume of the gases passed over or through the material in the upper part of the furnace in a given time. That was a kind of general law. If they could get the gas to pass in a straight line right and left, right away from, say, 20 feet wide above the

boshes, they would have the reduction effected along the whole line. Whether it passed very slowly right through a wide column, or quickly right through a deep column, it came to the same thing. But, unfortunately, there was a point at which the gases could not be induced to travel in a lateral direction. They always had a tendency to travel straight upwards. The shape, size, and position of the bell must have a very material bearing upon the working of the furnace. What Dr. Tosh had pointed out was very important indeed. Then there were the other conditions, the narrow furnace, the flat bosh, and the larger well. It was possible that the improvements made might be due to one or other, or to a combination of all those changes. Had they had a little furnace similar to the original furnace at Newport in a laboratory, they could have commenced on lines pretty much like those Mr. Williams had described. They could have started with an old furnace with a big well and straight shaft, and comparing that with an old furnace with a narrow well, they could then have narrowed the furnace, leaving the bosh as it was at the same angle; then they could have flattened the bosh, and tried that; and after having got all these results, they could have increased the size of the top of the furnace, and thus they would have obtained strictly comparative results. But, unfortunately, with large blast-furnaces they could not make elaborate experiments of that kind, and therefore were left a little more or less in the dark as to the actual cause of the increased make in those furnaces. His own impression was, that if the gases could only be made to pass through the whole expanded area of the materials in the upper larger parts of the furnaces, it would be a very important thing, and would undoubtedly result in economising, and thus save coke; and he believed that in the furnace with the bell and hopper as arranged at Newport, and with the material used there, that the economy effected was in certain measure due to this enlarged top; but whether economy would result in other furnaces out of the Cleveland district with bells differently arranged, only experiment would determine.

The PRESIDENT said they had had a very interesting discussion on Mr. Hawdon's paper, and on the new form of blast-furnace. He was bound to say that they were lines that he would never

have conceived, for one or two reasons. First of all, he thought it very difficult to get the gases to permeate the whole of the mass of material at the top of the furnace. They had been building for many years past the most powerful chimneys in order to draw the gases away from the furnace, so as to have as little back pressure at the top as possible. They knew that there was a considerable velocity at that point of the escaping gases, and that those gases would run the shortest way, straight in the direction of the outlet, not shown in the drawing; and he thought it would be found impossible that the gases could permeate the entire mass when they were rushing off at so great a speed. He did not know what the velocity was, but he knew it was very considerable. Then he did not approve of the vertical lines. He built a furnace like that once at Middlesbrough, perfectly vertical, 17 feet diameter at the top. If they were vertical, the materials had a tendency to pack themselves against the side of the furnace; but if the sides are tapered downwards, the materials, as they descended, unpack themselves. The angle of the bosh (68°) was rather too flat. At South Bank for many years the furnace which Mr. Evans had been speaking of had an angle of bosh of 65° , built by Mr. Dobbs. The furnace did not work with regularity. They found the material hanging on the flat bosh, but 75° was found a very suitable angle, and one they had adopted for a considerable time past, with a large crucible of 10 feet in diameter. The furnace described by Mr. Hawdon was working remarkably well. The results were extremely satisfactory, and they must accept that, and give Mr. Hawdon and Mr. Howson credit for having achieved such excellent results.

Mr. W. HAWDON, in replying, said with regard to what Sir Lowthian Bell had said about never having a solid pillar in the well, he (Mr. Hawdon) of course did not mean literally a solid one. If the furnace worked badly, and if there was too large a well, the materials became too solid in the middle, and it was difficult to get the blast to permeate. He did not intend to say that the whole of the reduction took place at the top of the furnace, but the bulk of it did. As regarded the deoxidation, Sir Lowthian said that it took place within 8 feet of the top: that

was not what they found. They found, as the members would see by the table, that it continued also very much lower down. With regard to Mr. Wood's remarks, he (Mr. Hawdon) did not say there was no necessity for the boshes; he said there was a necessity for the boshes. His words were, "We want it first in order to obtain capacity, and secondly in order to support the material." That was the very thing which Mr. Wood pointed out. As to the pressure of the blast they had been using, they were blowing now about $5\frac{1}{2}$ lbs. They were blowing about six when the results were given. They had tried the same pressure before, but found that with the coke they used they did not do such good work, or make any more iron, at the higher pressure than they did with the lower pressure. With the form of furnace described and with a larger well, they found that if they had a higher pressure they obtained an increased make. The furnace was not isolated. There were some isolated at the Newport Works, but that particular furnace was not. With regard to the fixed carbon in the coke, he took it that the mechanical condition of the coke was of more importance than the amount of fixed carbon in it. What he meant by fixed carbon was, that after the ash, the volatile matter, the moisture, and the sulphur had been deducted, the remainder was fixed carbon. The reason he had given fixed carbon was that those constituents varied in the coke they were using now and the coke they were using before. Therefore, if he were to give the members the amount of coke they were using now and the amount of coke they had used previously, as they were using about 1 to 2 per cent. more ash in the coke now than they were then, it would not be an unfair comparison to give the coke only. The iron could not be melted with the ash; it was the amount of fixed carbon which was required. The amount of fixed carbon in the coke they were using was about 82 to 83 per cent. The mechanical condition of the coke was about the same now as it was then. He understood Mr. Evans to say that there was not much difference between the cokes used in Durham; but they found there was a very considerable difference. They were using one coke with 11 per cent. of ash, which would carry more burden than another coke that had only $8\frac{1}{2}$ per cent. of ash, showing that the mechanical condition had a vast deal to

do with the matter. In comparing those cokes, it was, of course, very difficult to arrive at a true comparison, because with a soft coke there might be a higher amount of fixed carbon than there was in a harder coke, and yet the harder coke with the larger amount of ash did the most work. Mr. Evans had mentioned lime. He (Mr. Hawdon) had mentioned in his paper that they had tried burning lime in the Newport furnaces, and that the results did not justify a continuance of it. By that he meant that the amount of coal required to burn the lime cost as much as was saved in coke. Therefore it was not worth while doing it; but they found now, working with those lines—due, he thought, to the more rapid driving—that it paid to burn the lime, so far as they had been able to tell at present. Mr. Roberts asked the diameter at the tuyeres. The wall was 11 feet in diameter. Mr. Roberts also said he thought a larger bell would do better work. They had tried smaller bells, and were going on to smaller ones still, because they thought they did the better work. With a furnace constructed with the upper bosh or shoulder, when a larger bell was used, the small material was thrown to the side, and it was more apt to hang on the side of the shoulder; whereas if they had a smaller bell, the small material as it dropped from the bell fell more to the middle of the furnace. They thought the smaller bell was the better one. As to giving results in ten years' time, he could not guarantee to do that. The furnaces were new in each case when the results shown in the tables were taken. Mr. Williams questioned whether the large economy was due to the upper bosh, and would like a trial made of carrying the line of the barrel straight up to the top of the furnace. They were now building at Newport two furnaces for hæmatite, one with the lines straight up, and the other on the lines he had described in his paper. He should not like to build the particular furnace described with lines straight up, because the capacity would be reduced very much more than had been done already. He had endeavoured to point out that one reason for carrying it up on the top was to get capacity by making the barrel so very narrow as they had done, and he thought if they made it narrower they would do better. But, as Mr. Stead had said, they could not pull a blast-furnace to pieces and alter it

every day. They were obliged to go on very quietly with experiments, and if they carried the line straight up, they would reduce the capacity of the furnace to an extent they would not like to risk without further experiment. That was one reason why they extended the area at the top, by putting in this shoulder, to get the larger capacity. He could only say that "the proof of the pudding was in the eating;" and the furnace worked very well. The President had said that he thought the gases would not be diffused throughout the whole of the upper part. At Newport they had a back pressure of $\frac{3}{4}$ inch of water from the gases at the furnace top, and they could not have that back pressure without the gases filling the whole of the furnace. Therefore, he thought there was no difficulty about that.

CORRESPONDENCE.

MR. L. RICHARDS was of opinion that whatever portion of the weight of the column of materials that rested upon the area of the well in Mr. Hawdon's furnace, its large diameter and the short bosh, must be conducive to rapid driving; as the former exposed a proportionally larger surface of the materials to the action of the blast from the tuyeres, and as with the short bosh the materials had a less distance to slide over its inclined surface. It having been seen that the form of the bottom of the furnace might be made to account in part for the larger output from it, it became necessary to endeavour also to find out the cause why the furnace, reduced in capacity, had been able to produce the larger output, with a higher grade of iron, and with a marked saving in the percentage of coke, as compared with previous results, obtained in the same district from furnaces of larger capacity built upon the ordinary lines. It formerly was one of the great concerns of the blast-furnace engineer to endeavour to deliberate between having a furnace with a liberal capacity at the top part, and at the same time not to have the walls too near the perpendicular, as to interfere with the descent of the materials. But now it appeared from what was stated in the paper, that that was so much useless

trouble, as, in the furnace described, that part had been enlarged so as to make it considerably larger in diameter than any other part of the furnace, with most excellent results.

It was to be regretted that the author had not given more particulars concerning the furnace, especially as regarded dimensions, diameters, and heights, for then it would be possible to find how the capacity given was made up. It was evident that the rate at which the materials travelled in their downward course in the blast-furnace (neglecting mechanical changes) must be proportional to the horizontal cross section areas at the different levels throughout the height of the furnace. Hence it would at once appear how necessary it was to know the dimensions referred to. If it was assumed that the mean cross section area of the enlarged portion was, say, one and a half times the cross section area at its junction with the barrel, it might be asserted that the bulk of materials would remain within it a proportionately longer time, and that possibly a more complete reduction of the ores was brought about, which might account partly for the higher grade of iron in the larger output. But the reduced consumption of coke required an explanation also. That was, he presumed, for the most part a chemical question. There again information was wanted, for he could not find that the temperature of the escaping gases was given. Possibly the latter might be carrying away less of the sensible heat owing to the large bulk of comparatively cold materials they had to pass through just before their exit. Could it also be supposed that the lime used in place of limestone (which was credited in the paper with a saving of from 1 to $1\frac{1}{2}$ cwt. of coke) was less acted upon by carbonic acid, in this form of furnace than in the ordinary form?

Mr. HAWDON, in reply to Mr. L. Richards, stated that he had endeavoured in his paper to point out that the large area near the tuyeres induced rapid driving when the materials were properly and evenly prepared in the upper reaches of the furnace, which, he thought, was the case in the furnace in question. The saving in coke was brought about by having a large area in the reduction zone near the top of the furnace, and a contracted barrel, where the coke first passed rapidly down to the tuyeres, and where there

was not so much time for the carbonic anhydride in the gases to act on the carbon of the coke.

The PRESIDENT said he was sure the members would accord to Mr. Hawdon a hearty vote of thanks for his most interesting paper.

The vote of thanks was carried unanimously, and the following papers were read :—

THE PHYSICAL INFLUENCE OF ELEMENTS ON IRON.

By J. O. ARNOLD,
PROFESSOR OF METALLURGY AT THE SHEFFIELD TECHNICAL SCHOOL.

SECTION I.—HISTORICAL.

In the *Journal of the Iron and Steel Institute*, 1890, No. I., p. 38 *et seq.*, appeared a most remarkable and important paper on the physics of iron by Mr. F. Osmond, under the title of "On the Critical Points of Iron and Steel." At the time it was read before the Institute, this communication, owing to its complicated nature, received but meagre criticism; but on its deliberate perusal by steel physicists, it revealed the fact that with consummate skill Mr. Osmond had, with the aid of the beautiful pyrometer of Professor Le Chatelier, installed an admirable apparatus which had brought into the region of practical observation the details of the hitherto crudely observed phenomenon known as the recalescence of iron, first observed (in 1869) by Dr. Gore, and subsequently somewhat more closely investigated by Professor Barrett in 1873.

Mr. Osmond showed that there appeared to be three critical points or evolutions of heat on cooling a piece of very mild steel from a temperature of 1000° C.

1st. A slight evolution of heat at about 850° C., AR3.*

2nd. A very faint disengagement of heat at about 750° AR2 (this was regarded by Mr. Osmond as probably merely the retarded termination of the point AR3).

3rd. A point AR1, at about 650°, which was almost absent in very mild steel, but became highly accentuated in steels high in carbon, and was therefore due to a combination of iron and carbon

* The author has adopted in a modified form Mr. Osmond's nomenclature, which, however, is too complicated for every-day work. The terms AR1, AR2, and AR3 apply in this paper to the points, whether appearing as evolutions of heat on cooling or absorption of heat on heating, in the sense that the fall or rise of the pyrometer is arrested.

to form the definite carbide Fe_3C , discovered independently by Sir F. Abel and Dr. Müller.

Mr. Osmond, however, attached comparatively little importance to the last named, and in hard steel decisive evolution of heat and to the molecular changes evidenced thereby, but advanced the startling theory that the point AR3 marked the vital change-point of the passage into ordinary soft iron of an allotropic modification of iron (existing at temperatures above the critical point) of adamantine hardness. This alleged allotropic form Mr. Osmond named β iron, to distinguish it from α or soft iron. It was further stated that the almost diamond hardness conferred upon tool steel when plunged at a good red heat into cold water was due, not to carbon, but to the presence of β iron, rendered stable at low temperatures on being suddenly chilled in the presence of carbon, the last-named element as such possessing a comparatively insignificant hardening influence. It was also proved experimentally that the greater the percentage of carbon the lower the temperature at which the change-point AR3 took place, till in steels containing about 0.75 per cent. of carbon it became identical with or merged into the point AR1.

Further, Mr. Osmond announced that an investigation made on a series of alloys containing special quantities of the elements occurring in steel had verified Professor Roberts-Austen's law that the influence of elements on iron is in accordance with the periodic law—that is to say, the smaller the atomic volume of an element $\left(\text{atomic vol.} = \frac{\text{atomic weight}}{\text{specific gravity}} \right)$, the greater its power of hardening, or, in other words, of retaining the cold metal in the condition of β or hard iron.

Mr. Osmond, therefore, divided the elements into two groups, viz., first, elements the atomic volume of which was smaller than that of iron, and which therefore tended to harden the iron, owing to rendering stable its β modification. Second, elements of atomic volume greater than that of iron, and which therefore tended to produce a more or less complete change of the iron on cooling into the α or soft form. Table I. indicates the division of the elements into their respective groups of hardening and softening substances.

TABLE I.

COLUMN I. Hardening or β Iron-Producing Elements.		COLUMN II. Softening or α Iron-Producing Elements.	
Name.	Atomic Volume.	Name.	Atomic Volume.
Carbon	3.6	Chromium	7.7
Boron	4.1	Tungsten	9.6
Nickel	6.7	Aluminium*	10.5
Manganese	6.9	Silicon	11.2
Copper	7.1	Arsenic	13.2
		Phosphorus	13.5
Iron	7.2	Sulphur	15.7

The elements in Column II. Mr. Osmond declared had an influence analogous to that of annealing.

As possible doubts might arise in the minds of steel metallurgists whether phosphorus really was one of the best elements to introduce for the purpose of producing soft steel castings, Mr. Osmond explained that where an element appeared to act in a manner contrary to the law laid down, such deviation must not be put down to any failure in the law, but to a perverse individual action of the element itself or the compounds formed by it. In further support of his theory, Mr. Osmond stated that the point AR3 had been identified in a highly satisfactory manner with the appearance and disappearance of magnetism in nearly pure iron respectively on cooling or heating.

He also quoted the hardness and non-magnetic properties of Hadfield's manganese steel as an experimental proof of the accuracy of the theories enunciated. (The author understands that Mr. Hadfield himself will make a communication to the Institute with reference to the magnetic properties of his alloy.)

The abstract charm of the new theories caused them to be gradually accepted and taught by theoretical metallurgists, notwithstanding the fact that the authors of the hypotheses had entirely ignored the microscopic work of Dr. Sorby on the crystalline structure of iron and steel.

It is satisfactory to note that such well-known metallurgists as Hadfield in England, and Professors Howe and Ledebur in

* This element was not dealt with by Mr. Osmond.

America and Germany, refused to desert the standard of carbon.

The first decisive attack on the β iron theory was made by the author at the meeting of the Institution of Mechanical Engineers, convened to hear the first report of Professor Roberts-Austen on the work of the Alloys Research Committee appointed by the Institute. In opening the report, it was remarked that naturally iron and steel were the metals the alloys of which would be of most interest to members, but that the difficulties of obtaining commercial masses containing practically only one element were very great. Professor Roberts-Austen also adopted *en bloc* Mr. Osmond's conclusions, after having experimentally verified some of them by means of an admirably designed autographic recorder. But he thought that the best method of absolutely proving them, would be to endeavour to obtain experimentally hard allotropic modifications of lead and silver as analogues, rather than to proceed with the investigation on iron itself.* Upon this view the author made an uncompromising attack, and also pointed out that an autographic curve exhibited, which had been obtained from a sample of steel of medium hardness, did not at all bear out the Beta iron theory.

Taking for granted the accuracy of the opinion of Mr. Osmond and Professor Roberts-Austen, that the points AR3 and AR2 were really one, the author put forward as a tentative hypothesis that the upper point marked a change from a plastic to a crystalline condition, not necessarily involving any allotropic change of the nature described by Mr. Osmond. In reply to this, Mr. Osmond stated that the crystallising point of iron had nothing whatever to do with the critical points ARS 1, 2, and 3, as it occurred above 900° C. On April 20, 1893, Professor Roberts-Austen presented to the Institution of Mechanical Engineers the second report of the Alloys Research Committee, and therein reiterated his assertion of the probable truth of the Beta iron theory. The author, meanwhile, had carefully studied during a period of over a year the critical points occurring in mild steel, and pointed out to the members of the Institution, as the result of his investigations, that the point AR2 was not in any way connected with

* *Proceedings of the Institution of Mechanical Engineers*, 1891, p. 545.

the point AR3, inasmuch as it possessed altogether distinct properties, because—1st. It was practically unaffected by the initial temperature from which the steel was cooled; whereas, as Mr. Osmond had already pointed out, AR3 was distinctly lowered when the steel had been heated to a very high initial temperature. 2nd. That it was a truly reversible point, evolving heat during cooling, and absorbing heat during heating at practically the same temperature; whereas, as previously pointed out by Mr. Osmond, the absorption of heat due to the points AR1 and AR3 invariably appeared at a higher temperature than the evolutions of heat taking place on cooling. From the facts that AR1 and AR3 possessed similar properties, and that the former was known to be due to a chemical cause, the author suggested that AR3 also might be proved to be of chemical origin, and put forward as a tentative hypothesis the possible influence of the element hydrogen, at the same time quoting the results of an experiment the details of which will be hereinafter given, which seemed to negative this view. He also quoted some experimental evidence he had obtained which strongly favoured the view that AR2 was a physical point due to the passage of hot iron from a plastic to a crystalline condition. (Further experiments confirming the views then expressed will be found in the present paper in the recalescence section.) At the same meeting Mr. Hadfield and the author both urged that the Beta iron theory had no foundation in fact, and that the phenomenon of the hardening of steel depended almost entirely upon the influence of carbon alone. In reply, Professor Roberts-Austen stated that Mr. Hadfield had not grasped the difference between mass hardness and atomic hardness, and that a mass may be very hard whilst its atoms are very soft, and *vice versa*.* Mr. Hadfield's ignorance on this point is shared by the author; and the illustration quoted by Professor Roberts-Austen to prove his enunciation is absolutely without bearing upon the point at issue. He stated that some silver was so brittle that it would not roll, therefore its mass was hard; but that, nevertheless, individual crystals from the piece flattened easily, therefore its atoms were soft.

It is obvious that the incapability of the metal in question to

* *Proceedings of the Institution of Mechanical Engineers*, 1893, p. 187.

withstand the operation of rolling was due not to hardness in the sense used by Professor Roberts-Austen, but to a lack of cohesion between the facets of the crystals.

Mr. Osmond, in reply to the author's contribution to the discussion on the second report of the Alloys Committee, admitted the accuracy of the author's contention as to the existence of AR2 as a separate point, and stated that he had himself, previous to the author's communication, separated it from AR3, on finding that AR2 was the point at which magnetism appeared and disappeared in iron on cooling or heating respectively.* Mr. Osmond, in a qualified manner, also admitted the possibility of the accuracy of the author's determinations of the crystallising point of iron, but stated that the experiments had really proved the existence of a third allotropic modification of iron, of unknown properties, which he proposed to call Gamma iron. Mr. Osmond concluded his communication with the remark that the result of the author's recalescence investigations had only furnished additional reasons to Beta iron theorists to maintain their views more tenaciously than ever.

The author was pleased to note amongst the correspondence on the second report the sound general views expressed by Mr. André Le Chatelier on the great influence of crystalline form on the properties of metals.

At the present time, when applied science has just succeeded in gaining admission to the workshop, and is gradually commanding the confidence of the workman, it is of the highest importance that the faith of practical men in scientific guidance should not be shaken by the enunciation of theories which are opposed to the results of every-day experience; neither should students of iron metallurgy be instructed in hypotheses which may place upon an erroneous basis the fundamental principles involved.

After Professor Roberts-Austen's reply to the discussion on the second report, in which he expressed his great satisfaction at the extent to which the theories promulgated by Mr. Osmond and himself were being taught in schools of metallurgy, the author felt that the time had come when the Beta iron hypothesis should be either experimentally demonstrated or disproved.

* Professor Roberts-Austen, in his second report, ignored the existence of the point AR2.

SECTION II.—CHEMICAL.

THE LINE OF RESEARCH.

The object of the research was to gain, if possible, decisive answers to two questions—

1. Is the influence of elements on iron governed by the periodic law as enunciated by Professor Roberts-Austen?

2. Is there an intensely hard allotropic modification of the metal iron as stated by Mr. Osmond?

The author felt that the above problems could only be satisfactorily solved by a direct attack on the line unnecessarily rejected by Professor Roberts-Austen on account of its difficulty, viz., by the preparation of a series of alloys of practically pure iron with decisive quantities (1 to 2 per cent.) of the various elements.

The difficulties which had to be encountered in obtaining the series above mentioned in sound ingots of commercial dimensions, and capable of being cleanly rolled, were of course considerable.

(a.) On account of the very high temperature it was necessary to maintain for several hours to reduce appreciable weights of nearly pure iron to a perfectly fluid state.

(b.) The difficulty of introducing in a pure form all the elements required.*

(c.) The manufacture of large crucibles sufficiently refractory to withstand the highest temperature obtainable by the combustion of coke in air, and at the same time of such a composition as to throw only traces of impurities into iron at a temperature of about 1700° C.

(d.) The difficulty of avoiding the introduction of oxygen into some of the alloys, the result of such introduction being red-shortness in the rolls.

The means by which the above difficulties were finally overcome form an interesting chapter in practical steel metallurgy, but they are not connected in detail with the present paper. The first point to be decided was to select the purest obtainable iron as a base for the preparation of the alloys, and the brand known as

* In this matter the author is greatly indebted to Mr. Hadfield, who cheerfully sacrificed some of his most treasured alloys and pure metals on the altar of this research.

"Little S," which is obtained by the Lancashire hearth process from mottled iron smelted from middle bed Dannemora ore, was finally selected. The average analysis of this material was found to be as follows:—

Carbon	0.03
Silicon	0.02
Manganese	0.07
Sulphur	0.005
Phosphorus	0.015
Iron and oxygen by difference	99.86

The ingots, weighing 25 lbs. each, were cast about 2 feet 6 inches long and $1\frac{3}{4}$ inch square, in stout iron moulds, so as to set very quickly, and thus prevent any possibility of liquation of any portion of iron richer in the alloying element than the main body of the ingot. The alloy of sulphur and iron, which, of course, would not roll, was cast in dry composition moulds in four bars 12 inches long by $1\frac{1}{2}$ inch diameter, all run from the same head. For comparison with the tests obtained from the sulphur alloy a corresponding mould of the nearly pure iron was cast. All the ingots and bars were perfectly sound, owing to the addition of one-tenth per cent. of pure aluminium to the contents of each crucible shortly before casting. The standard of purity aimed at was: carbon not to exceed 0.1 per cent., silicon not to exceed 0.05, manganese not to exceed 0.1, sulphur and phosphorus each not to exceed 0.02 per cent. It will be seen that the above standard was obtained in nearly every case: all the ingots were rolled from $1\frac{3}{4}$ inch square into 1 inch round bars. The latter were in every case clean and sound. The analyses and specific gravities of the alloys obtained are set forth in Table II.

It is extremely unfortunate that it was not found possible in the case of the manganese alloy to prevent the passage into the steel of silicon from the crucible. At first, also, the unavoidably high carbon (0.17 per cent.) in the chromium alloy was a cause of regret, but, as will be seen later, its presence turned out to be very instructive.

TABLE II.—*Table Showing Chemical Compositions and Specific Gravities of the Alloys.*

The analyses were made on drillings taken from the centre of each bar.
 The results are stated to the nearest $\frac{1}{100}$ per cent.
 The specific gravities were determined by weighing in air and water polished blocks of the normal alloys 1 inch long by $\frac{5}{8}$ inch diameter.

Alloy.	Special Element. Per Cent.	Carbon. Per Cent.	Manganese. Per Cent.	Silicon. Per Cent.	Sulphur. Per Cent.	Phosphorus. Per Cent.	Aluminium. Per Cent.	Iron by Difference. Per Cent.	Specific Gravity.
Iron (rolled) .	99.87	0.04	0.02	0.03	0.02	0.02	0.00	99.87	7.8477
Iron (cast) .	99.82	0.08	0.01	0.04	0.03	0.02	0.00	99.82	7.8478
Nickel . . .	1.51	0.11	0.09	0.03	0.03	0.02	0.02	98.39	7.8538
Manganese . .	1.29	0.10	1.29	0.37	0.02	0.02	0.03	98.17	7.8269
Copper . . .	1.81	0.10	0.08	0.04	0.02	0.02	0.03	97.90	7.8661
Chromium . .	1.10	0.17	0.02	0.02	0.02	0.02	0.03	98.62	7.8486
Tungsten . .	1.41	0.08	0.14	0.02	0.02	0.02	0.02	98.29	7.9141
Aluminium . .	1.85	0.03	0.04	0.05	0.02	0.02	1.85	97.99	7.6756
Silicon . . .	1.94	0.08	0.11	1.94	0.02	0.02	0.06	97.77	7.7328
Arsenic . . .	1.57	0.04	0.01	0.03	0.02	0.03	0.03	98.28	7.8690
Phosphorus . .	1.36	0.07	0.02	0.03	0.02	1.36	0.03	98.47	7.7978
Sulphur . . .	0.97	0.08	0.00*	0.03	0.97	0.02	0.03	98.85	7.6903
Tool steel† .	1.35	1.35	0.28	0.08	0.02	0.02	0.04	98.21	7.8128

It will be observed that boron, the element which Mr. Osmond and Professor Roberts-Austen classified as next to carbon in its Beta iron-producing power, is absent from the list. The evidence upon which it was assigned so prominent a position in the column of alleged hardening elements was, in the author's opinion, of the most trivial and unsatisfactory nature. A button of iron weighing about 4 grammes was electrically fused *in vacuo* with fragments of diamond boron. On this insignificant piece of metal, recalcination tests were carried out, but apparently no attempt was made to prove analytically that it really contained combined boron. Mr. Osmond found that the point AR3 was distinctly lowered, and hence concluded that the action of boron on iron was similar to that of carbon. To attempt to properly investigate this point the author prepared several ounces of crystalline boron by maintaining for eight hours at an intense white heat a mixture of pure metallic aluminium and boron trioxide placed in a large graphite crucible. The crystals obtained readily scratched glass

* It is interesting to note that the sulphur has eliminated every trace of manganese.

† This was selected as a standard of comparison for the alloys, and will be hereinafter referred to as the carbon alloy.

and alloyed with platinum at a red heat, forming fusible globules of the boride of that metal. On analysis, however, the crystals proved to contain 14.6 per cent. of aluminium. Two and a half ounces of these crystals were packed in a thick paper cartridge, and were saturated with a readily decomposable hydrocarbon oil, to produce at the moment of addition a non-oxidising atmosphere. The closed cartridge was added to 9 lbs. of the nearly pure iron in a perfectly fluid condition, and the cover of the crucible quickly replaced. In ten minutes the ingot was cast and was subsequently rolled into a bar. On analysis, large weights of the drillings failed to give any qualitative evidence of the presence of boron. The paper and oil of the cartridge had raised the carbon to 0.12 per cent., to which percentage the mechanical, microscopical, and recalcence tests made on the bar corresponded. In brief, boron does not readily alloy with iron, with conditions under which carbon, and even the volatile elements, arsenic, phosphorus, and sulphur, combine with avidity. The boron which should theoretically have been present in the bar obtained was $1\frac{1}{2}$ per cent.

The author naturally planned this investigation on the lines he has for many years advocated for iron and steel researches, namely, correlation. The sections embodied will be found to be chemical, mechanical, microscopical, and physical. It will also be seen hereinafter that in several cases the results obtained by any three of the methods would have been incomplete, and likely to lead to inaccurate conclusions, in the absence of the facts revealed on investigation by the fourth line of observation.

SECTION III.—MECHANICAL.

DEFINITIONS.

In an investigation like the present one, it is of the greatest possible importance that the various tests should be strictly comparative. For instance, in a recent important research the correlation of the microscopical and mechanical tests was rendered almost valueless from the fact that the latter were made on one-inch round rolled bars, whilst the former had reference to quarter-inch square hammered bars.

Also when pieces of the same metal, after being subjected to varying thermal treatment, are under examination, it is necessary that the definitions of the various treatments applied should be explicitly stated. They are as follow :—Throughout the present paper the term “*normal*” has reference to the rolled bars raised to a temperature slightly over 1000°C ., and then allowed to cool in air, so as to re-crystallise the alloy and obtain the structure free from any possible crystalline distortion which may have occurred during the rolling, if during the last pass the temperature of the bar had fallen below 750°C .

The term “*annealed*” has reference to bars heated (in a covered cast-iron box packed with a mixture of white sand and fire-clay) on the bed of a reverberatory furnace to a temperature slightly over 1000°C . for seventy-two hours, and then allowed to cool in the luted furnace, so as to be capable of being handled in about an additional 100 hours.

The term “*hardened*” has reference to bars quenched out in a considerable volume of fresh cold water from a temperature slightly exceeding 1000°C . (See further details under Bending Tests.)

The author has previously pointed out* the existence of two kinds of hardness, to which he applied the terms “brittle” (or inter-crystalline) hardness and “abrasion” (or molecular) hardness. Metals possessing brittle hardness may be quite soft under the drill, and yet break quite short under the influence of a sudden shock. A metal possessing abrasion hardness resists the attack of a drill, but is also very liable to snap under the impact test.

In the present investigation the hardness assumed by the various alloys under the most favourable conditions, for the retention of the iron in its alleged β form (viz., when quenched out in cold water from a temperature over 1000°C .), was measured in two ways :—

1st. By bending quenched bars 5 inches long and $\frac{3}{8}$ inch diameter in a steel block over a radius of $\frac{5}{16}$ inch.

2nd. By compressing small quenched blocks of the alloys 0.564 inch diameter by 1.13 inches long.†

The whole of the test-pieces used throughout the research were

* *Proceedings of the Institution of Mechanical Engineers*, 1891, p. 585.

† The bars and blocks before quenching were heated under a covering of lime on the floor of a cupelling muffle.

machined from the centres of the original inch bars, so as to exclude the possibility of the results being interfered with by external oxidation effects. This precaution was more particularly necessary in view of the prolonged heating indispensable to obtain the maximum annealing effect.

TENSILE TESTS.

The tensile tests were made on a 50-ton Wicksteed single-lever machine. The diameters were read off to $\frac{1}{1000}$ of an inch. The elastic limits given are the permanent set points taken with a pair of fine dividers. The results obtained from the normal alloys are embodied in Table III.

TABLE III.—*Table of Tensile Tests on the Normal Alloys.*

Test bars 0·564 inch diameter (0·25 inch area) and 2 inches parallel.

Alloy.	Special Element. Per Cent.	Carbon. Per Cent.	Iron. Per Cent.	Total Impurities (including Carbon). Per Cent.	Elastic Limit. Tons per Square Inch.	Maximum Stress. Tons per Square Inch.	Elongation. Per Cent.	Reduction of Area. Per Cent.	Remarks on Fracture, &c.
Iron *	99·87	0·04	99·87	0·13	14·39	21·77	47·0	76·5	Fine grey granular, silky edges, cup and ball.
Carbon *	1·35	1·35	98·21	0·44	46·53	57·50	5·0	5·6	Finely crystalline.
Nickel *	1·51	0·11	98·19	0·30	22·45	26·80	35·3	62·0	Fine grey granular, ragged silky edges.
Manganese *	1·29	0·10	98·17	0·54	22·72	32·16	35·0	65·0	Fine grey granular, silky edges, cup and ball.
Copper *	1·81	0·10	97·90	0·29	30·80	34·80	30·5	62·2	Fine grey granular, silky edges, cup and ball.
Chromium *	1·10	0·17	98·62	0·28	19·75	27·18	40·0	72·1	Fine grey granular, silky edges, cup and ball.
Tungsten *	1·41	0·08	98·29	0·30	20·00	27·24	42·5	76·6	Fine grey granular, silky edges, cup and ball.
Aluminium *	1·85	0·03	97·99	0·16	17·00	27·04	35·0	63·7	Fibrous; crystals drawn from shoulder.
Silicon *	1·94	0·08	97·77	0·29	20·40	31·68	36·0	62·4§	Almost rectangular, otherwise same as above.
Arsenic *	1·57	0·04	98·27	0·16	17·75	27·10	28·5	34·1	25 per cent. grey granular, 75 per cent. crystals.
Phosphorus *	1·36	0·07	98·47	0·17	28·98	28·98	0·0	0·0	Large crystals.
Sulphur †	0·97	0·08	98·85	0·16	2·54	2·54	0·0	0·0	Bright granular.
Iron †	99·82	0·08	99·82	0·18	14·28	20·08	16·0	33·8	Coarse and pale grey in colour.

* Test-pieces from rolled bars.

† Test-pieces from cast bars.

‡ Exclusive of carbon.

§ Approximate only, owing to the test-piece being almost square at the point of fracture.

CONSIDERATION OF RESULTS.

It will be seen at a glance that, without exception, the alloys are harder than the pure iron, which exhibits remarkable ductility. The unique effect of carbon will also be noted. The manganese test is not of much value as a measure of the effect of that element upon iron, owing to the large amount of silicon present. It is probable that, in the absence of silicon, manganese would group itself with chromium and tungsten in their comparatively small reduction of the ductility of the iron. Another point worthy of attention is the utterly different effects upon the iron of the two closely related elements, arsenic and phosphorus.

The behaviour of the sulphur alloy (which must be compared with the test of the iron as cast) constitutes perhaps the most remarkable feature of the table. A point of some practical interest will be found in the comparative tests of the iron as cast and after rolling. A significant fact is recorded with reference to copper. This element, the atomic volume of which is practically identical with that of iron, should, according to the periodic-law theory, have little or no effect. It has, however, considerably hardened the iron, much more so than nickel, which is alleged to rank next to carbon in hardening power. Finally, the effect of phosphorus, which should, theoretically, have a softening influence, owing to its extraordinary capability of producing α iron, speaks for itself.*

BENDING TESTS.

The results obtained by this method are very important in their bearing on the special subjects of this research, inasmuch as in the hardened bars exist the conditions most favourable for the detection of the alleged influences of the elements in retaining the iron in one or other of its supposed allotropic modifications. The masses of the alloys used were small; they were raised to a temperature far above all the critical points, and they were quenched out with great rapidity in a large volume of unaired cold water in the following manner. The test-bars were raised

* Mr. Osmond even went so far as to assert that in the presence of phosphorus iron was incapable of assuming any but the soft or α form.

to an incipient white heat (about 1100° C.)* in a cupelling muffle. A large bucket of cold water (renewed for each bar) was supported near the mouth of the furnace, and the pieces were plunged into the water and retained in rapid motion till cold. The temperature of immersion was certainly over 1000° C. The figures obtained are set forth in Table IV.

TABLE IV.—*Table of Cold Bending Tests.*

Test bars 5 inches long, $\frac{3}{8}$ inch diameter, bent over a radius of $\frac{1}{16}$ inch.

Alloy.	Special Element. Per Cent.	Carbon. Per Cent.	Iron. Per Cent.	Total Impurities (including Carbon). Per Cent.	Atomic Volume of Special Element.	Bending Angles.		
						Hardened.	Normal.	Annealed.
Iron†	99.87	0.04	99.87	0.12	7.2	180° unbroken	...	...
Nickel†	1.51	0.11	98.19	0.30	6.7§	180° unbroken	...	...
Manganese†	1.29	0.10	98.17	0.54	6.9§	180° unbroken	...	...
Copper†	1.81	0.10	97.90	0.29	7.1§	180° unbroken	...	...
Chromium†	1.10	0.17	98.62	0.28	7.7||	103° broke	180° unbroken	...
Tungsten†	1.41	0.08	98.29	0.30	9.6||	180° unbroken	...	...
Aluminium†	1.85	0.03	97.99	0.16	10.5||	180° unbroken	...	...
Silicon†	1.94	0.08	97.77	0.29	11.2||	180° unbroken	...	...
Arsenic†	1.57	0.04	98.27	0.16	13.2||	29° broke	180° cracked	180° unbroken
Phosphorus†	1.36	0.07	98.47	0.17	13.5||	0° broke	...	0° broke
Sulphur†	0.97	0.08	98.85	0.16	15.7||	0° broke	...	0° broke
Iron†	99.82	0.08	99.82	0.18	7.2	125° cracked	...	180° unbroken

It is a remarkable fact that the three hardened bars supposed to contain elements more or less powerful in their β iron-producing properties have all bent double without any sign of fracture; the manganese-silicon alloy being, however, remarkably stiff.

The failure of the chrome alloy may be attributed to the hardening influence of most of the comparatively high percentage of carbon present being retained by the influence of the chromium in the hardening form, as the normal bar bent double with ease.

The silicon alloy, though bending double without any sign of a flaw, ranked next in stiffness to the manganese-silicon bar.

* The temperature was approximately measured by melting buttons of silver and copper.

† Test-pieces from rolled bars.

§ Alleged hardening elements.

‡ Test-pieces from cast bars.

|| Alleged softening elements.

Curiously enough, when the three elements supposed to be most efficient in producing a or soft iron were reached, the bars began to break; only one giving any angle at all.

The arsenic alloy presents a faint resemblance to carbon steel inasmuch as the normal alloy answers distinctly to the influences of hardening and annealing. The alloys of phosphorus and sulphur are hopeless—a thorough annealing having in no degree altered their objectionable properties.

The process of annealing has considerably increased the ductility of the iron as cast.

It was not thought worth while to put the carbon alloy through this test, its properties being obvious and well known. A very small bending angle would have been obtained from the normal bar slightly increased by annealing, and the hardened bar would not have bent at all.

CRUSHING TESTS.

The compression tests were made on the Wicksteed machine between dead-hard steel plates. The sections of 0.25 inch area were submitted to a uniform maximum stress of 25 tons. The compressions were read off at every 2.5 tons by means of a vernier cutting to $\frac{1}{1000}$ of an inch. The results, which are detailed in Table V., are singularly instructive. The most important are also plotted in curves on Plate XIV. The normal curves of nickel, chromium, and tungsten are plotted on one line, as the divergences between the three in no case exceeded 0.005 inch.*

An interesting feature in the table will be found in the "Remarks" column. Wherever the samples have presented an uneven surface, the microscope showed the presence of large crystals of varying constitution. It is evident that during the test the harder crystals are forced through the softer areas, hence the rough appearance.

* Similarly it will be seen later on that a single drawing served to illustrate the micro-sections of these three alloys.

TABLE V.—*Table of Crushing Tests on the Normal and Hardened Alloys.*

Test-pieces 0·564 inch diameter (0·25 inches area), and 2 diameters (1·13 inch) long.

N = Normal. H = Hardened.

Alloy.	Special Element Per Cent.	Carbon, per Cent.	Compression per Cent. at Tons per Sq. Inch.												Remarks.
			20		40		60		80		100				
			N.	H.	N.	H.	N.	H.	N.	H.	N.	H.			
Iron* . .	99·87	0·04	5·8	1·3	25·2	12·8	43·8	30·5	55·3	43·8	62·4	52·2	N. Surface smooth, piece sound. H. Surface smooth, piece faintly flawed.		
Carbon* . .	1·35	1·35	1·3	0·0	3·0	0·0	8·4	0·0	20·0	0·0	33·0	0·0	N. and H. Surfaces smooth, pieces sound.		
Nickel* . .	1·51	0·11	3·5	0·0	17·3	8·0	35·8	17·3	49·1	33·6	57·0	44·3	N. Piece sound, surface smooth. H. Piece faintly flawed, surface smooth.		
Manganese*	1·29	0·10	1·3	...	11·5	...	27·9	...	43·0	...	52·7	...	N. Surface smooth, piece very slightly flawed.		
Copper* . .	1·81	0·10	1·3	...	8·0	...	22·1	...	38·5	...	49·6	...	N. Surface smooth, piece very faintly flawed.		
Chromium*	1·10	0·17	4·0	0·0	17·3	0·5	35·4	0·5	48·7	5·8	57·0	20·5	N. and H. Pieces almost sound, surfaces smooth.		
Tungsten*	1·41	0·08	3·5	...	17·3	...	35·9	...	48·7	...	56·6	...	N. Surfaces smooth, piece slightly flawed.		
Aluminium*	1·85	0·03	3·1	...	15·9	...	34·5	...	48·2	...	56·2	...	N. Piece decisively cracked, surface rough.		
Silicon* . .	1·94	0·08	2·2	0·0	12·0	2·7	27·5	11·5	41·2	23·9	50·5	35·0	N. Piece sound, surface rough. H. Piece faintly flawed, surface rough.		
Arsenic* . .	1·57	0·04	3·0	0·9	15·5	12·3	31·4	27·0	44·6	40·3	53·0	49·1	N. Piece sound, surface rough. H. Piece cracked, surface rough.		
Phosphorus*	1·36	0·07	0·7	0·0	3·0	0·9	8·9	5·8	20·8	13·6	26·1	23·0	N. Piece sound, surface rough. H. Piece faintly flawed, surface rough.		
Sulphur† .	0·97	0·08	6·7	...	36·7	...	58·4	...	65·0	...	69·5	...	N. Piece completely broken down and partially disintegrated.		
Iron† . .	99·82	0·08	6·2	...	26·1	...	44·7	...	55·3	...	61·5	...	N. Surface slightly rough and very faintly flawed.		

Note.—Pieces SiN, NiH, and AsH, were notably bulged from the circular form, and pieces CrH, SiH, and PH, were somewhat out of the vertical.

The author will allow to β iron theorists any advantage they may claim with reference to the fact that the sulphur alloy is apparently the softest of the series. Unfortunately for them, it is the only alloy which has to any serious extent disintegrated; also the micro-section proclaims it to be little better than a fine metallic sponge.

* Test-pieces from rolled bars.

† Test-pieces from cast bars.

It may be here remarked that the greatest care had to be observed in machining the test-pieces of the sulphur alloy, because, although very soft, it was so rotten (this somewhat objectionable adjective is the only one that truly describes it), that it fell into pieces between the lathe centres if anything approaching an ordinary cut were taken.

In the normal and hardened state pure iron has again maintained its ductile pre-eminence.

In the normal series the order of the elements in producing any hardening influence worthy of the name is, 1st, Phosphorus; 2nd, Carbon; 3rd, Copper and Silicon.

In the hardened series the slight hardening effect produced on the iron, nickel, arsenic, and phosphorus is no doubt due partly to the small amount of hardening carbon produced, and partly to altered crystalline structure.

The silicon alloy shows an appreciable increase of hardness.

The feature of the table which stands out in the strongest relief is the fact that the carbon hardness is to the extent of the test absolutely infinite, and quite incapable in its enormous intensity of being compared with the insignificant effects produced by the introduction of any other element. This is shown not only by the carbon alloy itself, but also by the remarkable effect produced by even 0.17 per cent. of carbon in the presence of an element like chromium, capable of retaining it wholly in the hardening condition.

The inconsiderable nature of the abrasion hardness produced in the whole of the other alloys may be exemplified by the fact that after the most drastic hardening they all filed with ease, and could be turned and drilled without difficulty (except, perhaps, the phosphorus alloy) with ordinary shop tools.

The author will here take the opportunity of acknowledging in well-earned terms of praise the valuable assistance of Mr. F. K. Knowles, who throughout the research has rendered the most able service, especially in carrying out the details of the melting, rolling, and mechanical testing of the alloys.

SECTION IV.—MICROSCOPICAL

(Sections used $\frac{1}{2}$ inch diameter $\times \frac{1}{16}$ inch thick, taken transversely from the centres of the original bars.)

Before going into the details of the varying crystalline forms exhibited by the present series of alloys, the author will make a few preliminary remarks on the progress of this method of examination, founded by Dr. Sorby more than thirty years ago. Since then, much work has been done, and many results have been published, but, as far as practical metallurgy is concerned, the matter remains where Dr. Sorby left it. For many years the author has made a close study of the subject with the advantages of Dr. Sorby's advice, and the possession of the classical series of sections upon which the original research was made; nevertheless, until the present paper, the fear of publishing ill-digested and misleading results has restrained him from making any public communication on the subject. Many of the figures published from time to time have been quite unintelligible to the writer, except that in some cases there was little doubt that appearances really due to mechanical imperfections and too vigorous etching were described as actual structure. It is also certain that, however useful for giving the observer a general and collective idea of the structural grouping of crystals, examination of iron and steel sections with low powers is useless, so far as the ultimate structure and the vital point of the condition of the crystalline junctions are concerned. The author has therefore been compelled to abandon photography as a means of recording the appearance of the micro-sections, because of the great difficulty in photographically illuminating opaque objects when employing objectives of short focal length. Also photographs represent more prominently the effects of imperfect polishing and etching than the actual structure itself. The sections herein figured have been polished* by the method described in Mr. Stead's paper on "Methods of Preparing Polished Surfaces for Microscopic Examination." The etching has been effected by very dilute nitric acid, varying in strength, according to the oxidibility of the alloy, from a mixture

* The author is much indebted to Mr. E. Barnes for the careful manner in which he polished this series of sections.

composed of 1 cubic centimetre of nitric acid, specific gravity 1.20, with 49 cubic centimetres of distilled water, to a mixture of about one-fourth that strength, namely, 1 cubic centimetre of 1.20 acid to 199 cubic centimetres of water. In certain cases it has been found very advantageous, after washing the etched section, to let it soak for a few minutes in a bath of benzole. This treatment seems to loosen the misleading film of oxide resulting from the etching, and on very gently rubbing the section for a few turns on fine wash-leather, it is obtained quite bright with the structure beautifully developed, and the metal, when mounted in an air-tight cell, is not liable to subsequently develop rust spots, which is the case when the benzole bath is omitted, owing to the slowly continuing action of the acid, the last traces of which are almost impossible to entirely remove by aqueous washing. The sections figured are strictly comparative as to size, all having been carefully drawn from the microscope at a uniform magnification of 600 diameters. Their description is as follows: the illumination being direct:—

NORMAL ROLLED IRON.

Plate XXII.

This section presents the usual appearance of nearly pure iron which has been submitted to fusion. The structure consists of polyhedral crystals, probably interfering octahedra and cubes.* These crystals are of two distinct types:—A. Smooth and bright areas, consisting of pure iron; B. Greyish rough areas with a mottled or wavy surface, due to the fact that they are more readily attacked by the acid: it is almost certain that in the last-named crystals a small percentage of carbon is localised; in addition to the above two components little knots of carbide of iron Fe_3C have liquated. The carbide being in a diffused form, etches dark, but here and there in the little patches may be detected the laminar structure of the crystallised carbide. In this section the author has purposely figured an appearance due to over-etching, namely, an apparent envelopment of some of the crystals in a layer of a

* Professor Roberts-Austen refers to the crystals of iron "as rounded polyhedra grains"—a somewhat misleading definition.

different substance. This has led Messrs. Osmond and Werth to propound their cell and cement theory. It is due to the fact that the acid has the greatest action on the edges of the crystals after it has once penetrated the joints, the consequence being that the separated edges reflect the light from their bevelled surfaces outside the illuminating mirror, hence the cemented appearance. It is obviously absurd to suppose that in the present case 0.04 per cent. of carbon could produce sufficient Fe_3C cement to join up the crystals in this section. The true appearance of fused iron is more accurately represented on Plate F., where a section as cast is shown. This, however, naturally contains rather more carbide knots, the carbon present being 0.08 per cent.

NORMAL NICKEL CHROMIUM AND TUNGSTEN ALLOYS.

Plate XXII.

One figure serves well to illustrate the structure of these alloys, except that the chromium shows rather more and the tungsten rather fewer carbide knots than the nickel alloy figured. The only palpable effect of the addition of these three elements on the iron has been to distinctly reduce the size of the crystals and to very decisively throw out a considerable number of carbide knots in the diffused form of that compound.

NORMAL MANGANESE-SILICON ALLOY.

Plate XXIII.

This section resembles the foregoing in the size of crystals, but the latter are much more irregular in form, presenting a number of needle-like points. This effect the author is inclined to attribute to the silicon unfortunately present, because the silicon alloy, Plate D., presents similarly formed crystals on a much larger scale.

NORMAL COPPER ALLOY.

Plate XXIII.

The crystals are like those of the nickel, chromium, and tungsten alloys, seeming, however, to be of two or three different compositions, though all more or less permeated with copper, as shown by the

uniform dark tint assumed by the section on etching. Some of the crystals are smooth and clear, others rough and mottled, whilst in the vicinity of the carbide knots occur groups of dark, oval granules, which the author believes to be nearly pure copper.

NORMAL ALUMINIUM ALLOY.

Plate XXIV.

This section presents very large crystals of two distinct types, namely, white and very pale brown in tint. The rough appearance noted on the outsides of the tensile and crushing test-pieces indicate that the above-named crystals vary in hardness, the darker type being probably very rich in aluminium. The crystals possess to some extent the dangerous property of individual contractile power, producing in a very modified form the remarkable effect shortly to be described with reference to the sulphur alloy. This circumstance accounts for the fact that the aluminium alloy was the only one of the rolled bars which developed serious cracks under compression.

NORMAL SILICON ALLOY.

Plate XXIV.

This alloy crystallised in very large irregular masses, consisting of two distinct materials. The white crystals are possibly poorer in silicon than the rough wavy type, which probably owe their appearance to the fact that they are more easily attacked by the acid than the smooth variety.

NORMAL ARSENIC ALLOY.

Plate XXV.

This alloy forms large crystals, differing in hardness owing to their varying richness in arsenic. Only very dilute acid could be employed for etching this section, as it became black with a coating of arsenide of iron on immersion in the stronger solution. During the etching a magnificent play of intense colours was noted. The cause of this was clear when the section was examined. To the author's surprise the metal contained a "pearly constituent" closely

resembling that discovered by Dr. Sorby in the case of carbon alloys, except that the arsenide striæ are much softer than carbide of iron. In addition to the laminated kind, there are white, red, and green crystals, according to the percentage of arsenic in them, and consequently of the thickness of the arsenide film. In some areas the striæ are imperfectly developed, giving the crystal a rough mottled appearance. It may be mentioned that on dissolving the alloy in dilute hydrochloric acid, a large black residue of arsenide of iron remained, hardly soluble even after long-continued boiling. The same remark, however, also applies to the phosphorus alloy. The completely different effects of arsenic and phosphorus (two elements practically identical in their atomic volumes, and presenting strong analogies in their chemical behaviour) upon the mechanical properties and the crystalline structure of iron show clearly the futility of building up theoretical analogues as guides to the properties of steel.

NORMAL PHOSPHORUS ALLOY.

Plate XXV.

This alloy also developed very slowly a play of colours on etching, but the stronger acid had to be used. The crystals are of (microscopically) very large dimensions, so much so that it is impossible to get a single crystal into the field at 600 diameters. The figure shows a point of junction of three crystals. The latter vary in colour like those of arsenic, but present a rough mottled appearance, in which no striæ could be detected. The crystalline joints seem to be readily penetrated by the etching acid.

IRON (AS CAST).

Plate XXVI.

This section has already been referred to. In etching, *cæteris paribus*, the crystalline junctions seem (judging by the comparative penetrative power of the acid) less cohesive than those of the rolled bar.

SULPHUR ALLOY (AS CAST).

Plate XXVI.

The mechanical vagaries of this alloy were at once explained on examining the section under the microscope. The large crystals appeared to be of one type, through which the sulphides of iron seemed fairly evenly distributed, but they evidently possess an extraordinary power of individual contraction, the result being that large fissures are developed between the joints in such numbers that the metal is almost cut into pieces. In some instances actually detached crystals may be observed, and many such fell out during the compression test in the form of a silvery dust. It is extremely improbable that the inter-crystalline spaces in cold steel, when due to the presence of sulphur, will weld up on heating; hence the red-shortness also produced by the presence of considerable quantities of this element. This micro-section forms a good example of the many cases occurring in metallurgy in which the study of molecules alone is of secondary importance when compared with the investigation of the junction lines of collective masses containing innumerable molecules and grouped into crystals.

SECTION V.—PHYSICAL.

RECALESCENCE.—INSTALLATION OF THE LE CHATELIER PYROMETER.

The recalcence pieces used in this research are considerably smaller than those usually employed by the author. The reason for thus reducing their size was convenience in subsequently using the bars in an investigation yet to be carried out on their magnetic permeability. A full-sized bar with the thermo couple *in situ* is shown in Fig. 1 (Plate XVIII.). The bar weighs about 130 grammes, is 4 inches long by $\frac{3}{8}$ inch diameter, recessed $1\frac{1}{4}$ inch by $\frac{3}{8}$ for the fire-clay couple leads, and also beyond this again recessed $\frac{1}{2}$ inch by $\frac{1}{8}$ inch for the couple chamber exactly in the centre of the bar. The piece *P* is supported at each end by thick circular fire-clay plates, just fitting the tube-muffle furnace *F* (Plate XVIII.). The bar having been placed in position and the tube well stoppered with asbestos,

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the furnace is fired with coke, and as the temperature rises the heating record is taken. The bar having reached the desired initial temperature, the damper *M* is closed, the fire-bars *B* are withdrawn to allow the fire to fall to the bottom of the furnace; it is raked out and the door *D* is shut, whilst the opening through which the bars were withdrawn is closed by means of the cast iron plug *X*. The furnace is then allowed to cool spontaneously, the cooling record being usually taken from 1000° to 600° . The couple is not in contact with the bar, a fact which considerably increases its life. The air-jacket round the test-piece was found to give great steadiness to the normal rise and fall of temperature during heating and cooling respectively. This furnace arrangement gives during the cooling a very even radiation. The insulated couple leads pass along a wooden bridge into the cold junction tubes *C*, which are filled with alcohol and surrounded by melting ice, thus doing away with the necessity of any correction for the temperature of the cold junction. The errors due to variations in the temperature of the galvanometer coil were found to be so minute as to make it pretentious to apply any corrections. The galvanometer *G* is supported in the camera box, and the table upon which is placed the latter stands on a concrete floor to prevent vibration. The source of light is a 5-candle incandescent lamp *L*; the lamp-box carries an adjustable lens fitted with a square diaphragm crossed by very fine platinum wire, which is focussed on the scale *S*. For the present series of alloys the apparatus was re-installed so as to give a deflection of 1 millimetre for 2.8° C. at the temperature of the critical points. The rates of rise or fall of the cross wire as it passes each division (and also stays) are electrically registered by means of the chronographic recorder *R* (shown on a larger scale in Plate XX.) from the keyboard *K* by means of a small code of signals. The travelling tape, worked by a claw lever attached to the central magnet, is perforated along the middle at intervals of about $\frac{1}{8}$ inch every second by means of a current from the clock. On the sides of the tape are pricked the records by making contact at the keyboard and transmitting a current round one or other, or both, of the side magnets as desired. The tape as used is wound off on the automatic winder worked by a weighted spindle. The above

arrangement constitutes a very delicate means of recording.* The scale was calibrated by means of melting ice, boiling water, boiling sulphur, boiling selenium, and melting normal potassium sulphate.

The curve is shown on Plate XV. It was found, as noted by Professor Roberts-Austen in his researches, that the zero on the scale was liable to change, though the deflections, as proved by occasional recalibrations, were constant. It was therefore deemed necessary to note the zero by immersing the couple in melting ice before and after every pair of experiments. The initial temperature of the coolings was arranged approximately from 1150° C. The tape records were translated into curves on the system originally used by Mr. Osmond, namely, the ordinates are the times occupied by the cross wire in passing one millimetre, and the abscissæ are degrees C. This system is very convenient for showing minute evolutions or absorptions of heat, but it should be remembered that the ideas conveyed to the eye by the curves are of an exaggerated nature, such exaggeration being readily increased by a suitable manipulation of the ordinates and abscissæ. In no case in the curves herein plotted was there any actual rise in the temperature of the metal, but merely a variation in the rate of rise or fall of the cross wire. But certain steels, high in carbon, give at the critical point AR1 an actual rise of 20° or 30° in the temperature of the steel on cooling. In such a case, the tooth in the curve obtained on this system of plotting would be nearly 2 feet long. In order to ascertain that the critical points were constant and concordant, a minimum of six observations, three heatings and three coolings, was made on each alloy. The accuracy of the method of observation is evidenced by the three cooling curves of the rolled iron given on Plate IV., the maxima of AR3 being concordant within one degree. The recorded absorption of heat on heating is always less than the recorded evolution of heat on cooling.

DEFINITIONS.

In this section the term "intensity" refers to the horizontal magnitude of the break in the curve. The term "amplitude" has

* The lamp and the various circuits are all worked from five storage cells.

reference to the vertical range of the points; in other words, it includes the degrees of rise or fall in temperature over which the evolution or absorption of heat is spread.

THE PROPERTIES OF THE CRITICAL POINTS.

The properties of the points ARS 1-2-3 (more particularly the constancy of AR2), previously referred to in the historical introduction to this paper, will be sufficiently obvious on an inspection of the various curves figured, especially those of the mild steel from ingot No. 261, the analysis of which is as follows:—C. 0.16, Mn. 0.05, Si. 0.04, S. 0.02, P. 0.02, Al. 0.01, Fe. by diff. 99.7 per cent. (The latter figure is inaccurately stated on Plate V. to be 99.63 per cent.)

THE CRYSTALLISING POINT OF IRON.

The details of the fourth series of determinations made of the crystallising point of pure iron are as follow:—Some plates, 3 inches by $\frac{1}{2}$ inch of unconverted Swedish bar iron (brand "DU" *), were piled, hammered to $1\frac{1}{4}$ inch square, and rolled down to 1 inch round, the rolling being arranged from such an initial temperature that the bar was finished at a just visible red, or practically black heat. From this bar pieces 2 inches long were cut and recessed for the couple in the manner already described with reference to the recalcence bars. The effect of prolonging the rolling to such a comparatively low temperature was found to be that in the longitudinal section the axes of the crystals were considerably elongated (at least 2 : 1) in a direction parallel with the slag fibres and pile lines.

Three of these pieces were connected with the thermo-couple in the usual way, and were, in the same manner as the ordinary recalcence bars, slowly heated up to the temperatures of 650° C., 750°, and 850° respectively, being then quickly withdrawn, and allowed to cool in the air. When cold, longitudinal micro-sections, half-inch square by one-tenth inch thick, were gently machined

* This particular lot of iron was selected on the ground that it contained considerable microscopical areas of perfectly pure iron crystals of large size. The total iron in the mean analysis of the bar was 99.8 per cent.

from the bars in the immediate vicinity of the couple chamber, as indicated in the full-sized sketch, Fig. IV. The black areas indicate the position from which each section was taken. On examining the polished and etched sections by direct light at 600 diameters, the following indications were observed, drawings being carefully made, crystal by crystal, from the microscope:—

Section Heated to 650° C.

This is figured on Plate A. The distorted crystals were not perceptibly changed in shape from those in the cold bar. An imperfect portion of the weld-line, appearing as a dark ragged fissure, is included to indicate the direction of the rolling.

Section Heated to 850° C.

This also is figured on Plate A. The structure presents the large, well-formed crystals characteristic of very pure wrought iron, showing that the distorted crystals had, between 650° and 850°, passed into a plastic condition, and had also been heated so far above the change point as to have time during the cooling to re-form in the normal manner.

Section Heated to 750° C.

This was similar in structure to that last described, but the crystals were on an average smaller, and the angles and facets were not so sharp and definite.

The recalescence curve of the foregoing iron showed the maximum of AR2 on heating at about 742°, the amplitude of the point ranging from about 720° to 750°; consequently, the heat of crystallisation capable of being recorded extended over a range of 30° C.

The above experiments Mr. Osmond does not regard as conclusive. They are the best the author could devise to solve a somewhat difficult problem, and he must therefore leave the matter to the iron and steel world for decision. Mr. Osmond states that iron crystallises above 900° C.; the author fixes the temperature at about 750° C. Practical iron and steel rollers should understand that Mr. Osmond's statement involves also an

assertion that all iron leaving the rolls at a temperature below 900° C. (a full red heat) has the crystals distorted in a direction parallel to the slag fibres. This condition is seldom or never found in either Swedish or English wrought irons, both transverse and longitudinal sections of the rolled bars presenting practically equi-axial crystals.

FURTHER CONSIDERATION OF THE CRITICAL POINTS.

Before going on to consider the recalescence curves obtained on heating and cooling the present series of alloys, it is necessary to make their indications more clear to study a little more closely the three critical points, already considered generally in the introduction to this paper. Concerning the point AR1, the author has proved beyond all doubt (in a research not yet ripe for publication) that its intensity is proportional to the Fe_3C present in a series of ascending carbon steels, and to the area of Sorby's laminae in their micro-sections. There is, therefore, no question as to the significance of this point. He has also pointed out that, from the experimental results obtained, he can only conclude that the point AR2 marks the exceedingly faint evolution or absorption of heat due respectively to the passage of the iron from a plastic to a crystalline condition or *vice versa*. It will be seen on inspecting the curves of the nearly pure iron that the point cannot be properly so called, but gives rise to a somewhat vibratory evolution of heat extending over a fall of about 30° of temperature, being thus in accordance with the generally preconceived idea of a progressive formation of the crystals.

The critical point concerning the cause of which the greatest difference of opinion exists is undoubtedly the point AR3. The author has previously referred to a case in which he had submitted an iron bar (No. 136)—similar to that forming the standard for the present series of alloys—but containing 0.06 per cent. of carbon, to a full white heat *in vacuo* for 17 hours, when it was still (at a vacuum of 29 inches of mercury) slowly evolving pure hydrogen.* The object of this experiment was to

* This experiment Mr. Osmond has described as "repeating" that of Professor Roberts-Austen, in which a fragment of electrolytic iron was stated to have evolved every trace of hydrogen before a temperature of 400° was reached.

ascertain the influence of a removal of hydrogen from the bar on the point AR3. The heating and cooling curves of the bar before and after heating *in vacuo* are figured on Plate V. (136). It will be seen that instead of diminishing the intensity of the point, the treatment has, both on heating and cooling, increased it, and raised the temperatures at which it appeared previous to heating. It should also be noted that the point AR1 faintly presented in the normal bar has disappeared. Mr. Osmond has quoted the result of this experiment as evidence "so strong as to be almost conclusive" of the accuracy of his theory that AR3 marks the β iron change point. Curiously enough, this very experiment was the first link in a chain of evidence so strong as to be almost conclusive that Mr. Osmond's theory is altogether wrong. Unlike Mr. Osmond, the author could not imagine that the removal of a very small percentage by weight of gases could so influence a physical change in the iron, but was rather inclined to attribute it to some internal chemical cause, connected with the long-continued heating of the iron at such a high temperature.

Accordingly, the recalescence piece from the iron as cast for comparison with the sulphur alloy was heated in a closed tube (not *in vacuo*) for twelve hours at a white heat. The recalescence curves (Plate XV.) will be seen to present the same differences before and after heating at a high temperature as the curves of the bar before and after heating *in vacuo*.

Another bar of almost pure iron, containing, however, 0.16 per cent. of carbon (marked 261), has its normal curves figured on Plate V. It will be seen that AR3 in the cooling has fallen almost to AR2, and that AR1 is well developed. A second bar of this material was annealed for seventy-two hours at a temperature below 1000°; the recalescence curves were not appreciably altered: it was then again annealed at a much higher temperature, the effect of which on the recalescence curves is figured on Plate V. 261 annealed. The point AR1 has almost disappeared. The point AR3 appears above the normal temperature at which it is supposed to appear in electrolytic iron. *In other words, the evolution of heat normally occurring at AR1 has, by the long-continued heating of the bar at a high temperature, been raised 200°, and augmented the heat evolved at AR3.* On analysis the annealed bar showed that only a very

superficial loss of carbon had occurred: the carbon of the main portion of the bar and that in close vicinity to the couple still registered 0.16 per cent. The above remarkable facts are satisfactorily explained by the hypothesis that the point AR3 marks the formation of a sub-carbide of iron, whilst the point AR1 is due to the combination of the elements to form the normal carbide Fe_3C , and that in low carbon steels a prolonged exposure to a white heat converts the normal into the sub-carbide. In connection with the above suggestion the author may mention that in a systematic research on "The Chemical Relations of Carbon and Iron," to be published elsewhere almost simultaneously with the present paper, Mr. A. A. Read and himself have shown that the result of their investigations are only satisfactorily explained by assuming the presence in the steels examined of a sub-carbide of iron in quantities rising as the carbon falls. The author has also found that the absorption of the point AR3 into the point AR1 is coincident with the practical disappearance of the sub-carbide.

ELECTROLYTIC IRON.

At first sight it seems that the author's tentative hypothesis, that the point AR3 is due to the chemical heat evolved by the formation of a sub-carbide, is at once decisively negated by the alleged fact that electrolytic iron also develops the point in its most marked and individualised degree. It is therefore necessary to weigh carefully the evidence published on this matter, when it will be found to be of the most trivial character. The electrolytic iron used by Mr. Osmond in his research may be at once dismissed, as he admitted that it contained no less than 0.08 per cent. of carbon, a quantity characterised by Professor Roberts-Austen as "a mere trace." Professor Roberts-Austen experimented upon a little piece of electrolytic iron (weight not stated) cut from a larger piece analysed by Mr. Riley, and by him found to contain 0.007 per cent. of carbon.*

The author unreservedly accepts Mr. Riley's decision. It was not stated, however, whether the iron was analysed in the form it

* Professor Roberts-Austen inclined to the view that this small amount of carbon was not in the iron itself, but was due to a "speck of dust."

came from electrolysis, or after heating, a point of possible importance. Upon this vital question as to whether electrolytic iron, supposed to be practically chemically pure, did or did not give a point at AR3, Professor Roberts-Austen has described only a single experiment, the result of which was abnormal. The autographic curve he exhibited showed no point at AR2, and indicated that the point AR3 appeared at a temperature of 850° C. both on heating and cooling. In no single case during the continuous experience of two years has the author (or, he believes, Mr. Osmond) found the point AR2 absent from nearly pure iron; also, no other record of the point AR3 occurring at 850° both on heating and cooling, is, as far as the author's knowledge goes, extant. This single experiment, however, constitutes the only evidence put forward that chemically pure iron gives an evolution of heat at the point AR3.

The author therefore deemed it absolutely necessary to re-investigate this important matter. Mr. Byron Carr, lecturer on electro-metallurgy at the Sheffield Technical School, kindly prepared for him a plate of electrolytic iron weighing 90 grammes and about $\frac{1}{8}$ inch thickness. This iron was deposited from a solution of pure ammonio-ferrous-sulphate, a bar of Swedish iron containing 0.04 per cent. carbon being used for an anode. Five grammes of the iron as prepared gave no residue except a fine reddish powder on being treated, first with a neutral solution of chloride of copper, and then with an acid solution of the same salt to dissolve the precipitated copper. Fifteen grammes of the iron, after heating the plate to redness, were then dissolved in a very dilute solution of hydrochloric acid in a galvanic circuit. A considerable residue, consisting of grey plates mixed with darker specks, was obtained. This was washed, dried, and burnt in oxygen in the ordinary way, but, as the author had reason to suspect the presence of sulphur, the gases after leaving the combustion tube were passed through potash bulbs, charged with a mixture of equal volumes of strong sulphuric acid and water saturated with chromic acid. The result of the combustion indicated the presence of 0.011 per cent. of carbon. This would, of course, be decidedly low, owing to loss as hydrocarbons during solution.*

* These discordant analytical facts may be explained on the supposition that a

Two plates of this iron were filed bright, and when finished weighed 8 grammes. The thermo-couple was placed between them, and the iron was enclosed between two fireclay plates, the whole being wrapped in asbestos. Four heatings and four coolings of the iron were then recorded. The points AR2 and AR3 seemed to be developed, both on heating and cooling, in their usual positions; but it was noted that the point AR3 on heating was abnormally well marked; also that with each successive cooling the position of AR3 fell a few degrees lower, till the difference in temperature between the first and fourth cooling was upwards of 20°. The point observed in the heatings, however, maintained its normal position.

It was next determined, if possible, to prepare an iron absolutely free from carbon by depositing the iron from a ferrous solution, and employing a platinum anode. A plate weighing about 50 grammes was thus prepared from a solution of equal weights of ferrous and magnesian sulphates, the solution being changed about every twelve hours as it oxidised, and the most favourable strength of current (previously determined by experiments) was steadily maintained by the interposition of a galvanometer in the circuit from the storage cells. The iron, which was perfectly bright, was well washed, dried, and heated to redness in a muffle-furnace, the piece being previously packed in an iron box in pure quicklime. The thermo-couple was placed between two plates of this iron, weighing together 20 grammes, the whole being well bound up in silky asbestos by means of platinum wire. Three heatings and three coolings were recorded as usual; exactly the same results were obtained as on the first sample. The position of AR3 on cooling fell lower with each successive experiment, whilst maintaining its position on heating (see Plate VI.). A combustion on 10 grammes of the plate after ignition in lime indicated the presence of 0.018 per cent. of carbon.*

On carrying the analysis further on the identical plates from which the recalescence curves were obtained, it was found that no

portion of the carbon from the anode traversed the solution and was occluded in the metal as hydrocarbons, the carbon in which became fixed only on heating the iron to redness.

* For the presence of this carbon the author can offer no satisfactory explanation.

less than 0.15 per cent. sulphur, *in the form of sulphide of iron*, was present. On reference to the recalescence tests on the sulphur alloy, it will be seen that the presence of sulphur has developed two new points never observed in the other alloys of iron, and also that the upper new point, though occurring at a considerably higher temperature, possesses exactly the same properties as the point at the temperature of AR3 observed in both electrolytic irons. Some further investigations were then made on sulphur alloys. The first fact noticed was, that in an alloy containing 0.06 per cent. of carbon and 2 per cent. of sulphur, the point occurring at AR3 in the first alloy became doubled in its intensity, the other four points being practically unchanged. On testing another alloy containing about 1 per cent. sulphur and 0.3 per cent. of carbon, utterly different curves were obtained both on cooling and heating. On cooling, a large carbon point appeared at 691° C., and above it another decisive evolution of heat at 748° . A faint point appeared about 871° , whilst an evolution of heat of considerable intensity appeared at a temperature of no less than 965° . In the heating curve AR1 appeared at 726° , whilst an equally large point was registered at 956° . In fact it is evident that the presence of sulphur itself gives rise to at least two points peculiarly its own, and where a little carbon is co-alloyed no less than five evolutions of heat occur. It is also clear that when the proportions of carbon and sulphur are varied, the positions of the points are so altered and discordant that their very identity is lost. (Experiments are now proceeding to endeavour to unravel this tangled skein.) The author, therefore, has very little doubt that the points at AR3, observed in the second sample of electrolytic iron, were due to the combined presence of nearly 0.02 per cent. of carbon and 0.15 per cent. of sulphur.

Professor Roberts-Austen, in describing his experiment with electrolytic iron, made no reference whatever to sulphur, and it is the author's opinion that the preparation of any considerable mass of electrolytic iron without sulphur is a matter of great difficulty, because unless a perfectly regular and solid deposition is maintained throughout the whole of the electrolysis, occupying several days, and the liquid is not kept clear from ferric salts, sulphur is

deposited in the iron either as sulphide,* or is involved as basic ferric sulphate, and on heating to a full red heat, practically the whole of the sulphur in the basic salt is absorbed by the iron.

The author cannot state absolutely that chemically pure iron only gives the point AR2, because such a metal has yet to be prepared and examined, but in the face of the evidence adduced, it can hardly be asserted that when 0.97 per cent. sulphur produces two distinctly abnormal evolutions of heat on cooling, that the presence of at least 0.15 per cent. will have no effect on the recalescence. To summarise, there is evidence of considerable weight against the appearance of AR3 in chemically pure iron, and practically no published evidence in support of the statement that such an evolution of heat does take place. Even should this be found to be the case, it is certain that the phenomenon has no mechanical significance. Electrolytic iron is an exceedingly unsatisfactory substance to experiment upon, and what is really wanted, is a bar of fused iron weighing several ounces, and registering on exhaustive analysis 99.99 per cent. of iron. The preparation of the above constitutes a metallurgical task of herculean difficulty.

THE POINTS OF RECALESCENCE OBSERVED IN THE ALLOYS.

The Rolled Iron.

Plate XV.

The rolled iron presents the well-marked point AR3 at 867° C. on heating, and at 846° on cooling. The point AR2 extends over 35°, and has two unequal maxima, the greater occurring at 743°, and the lesser about 725°. The point AR1 is absent, and unless it be asserted that 0.04 per cent. carbon evolves on cooling, no heat capable of registration by an exceedingly delicate instrument, the only alternative seems to be that the point at AR3 marks a formation of sub-carbide of iron.

* A piece of the author's second sample before ignition gave off, when dissolved in hydrochloric acid, a gas which blackened lead paper.

The Iron as Cast.

Plate XV.

This has already been referred to in the article dealing with the general properties of the critical points.

The Carbon Alloy.

The recalescence curve of this steel has not been herein plotted. It contains only a single point at 685° , giving a tooth about 1' 6" long during the cooling, and a large point on heating at 713° .

The Nickel Alloy.

Plate XVII.

The points ARS2 and 3 are combined on cooling at 742° , the heat evolved being abnormally great. This, in the author's opinion, is due to the formation of a carbide of nickel, of the existence of which some chemical evidence has been obtained. The point AR1, marking the formation of normal carbide of iron, occurs at 645° ; or about 40° lower than in the case of a pure carbon alloy. On heating, AR1 shows at 702° , AR2 at 733° , and AR3 at 808° .

The Manganese-Silicon Alloy.

Plate XVII.

On heating, AR1 appears at 722° , AR2 at 722° , AR3 is absent or dubiously present. On cooling, AR1 is shown at 626° , or about 59° below the point at which the carbide is formed in an iron and carbon alloy. The points ARS2 and 3 seem in this metal, on cooling, to have united into a slight but long-continued evolution of heat; commencing at 775° and becoming finally merged into AR1.

The Copper Alloy.

Plate XVII.

On heating, a combined point, presumably AR1 and AR2, appears at 716° . On the first cooling AR1 showed at 654° , or

31° below its normal position. A confused point extending from 785° to 710° is apparently a combination of AR2 and AR3. It was, however, found that on each successive cooling a different result was obtained, until at last, during the fourth cooling, the curve consists of a series of indefinite evolutions of heat extending from 800° to 600°, and due to the confusion of the heat evolved by the normal points with that due to the falling out of iron-copper alloys. These elements do not appear to remain truly alloyed at temperatures above the melting-point of copper. This view was confirmed by the microscopic examination, and also by the fact that when the scale was removed from the outside of the recalescence bar the latter was found to be partially coated outside with patches of pure copper. The above facts appear to have escaped the observation of Mr. Osmond in his researches.

The Chromium Alloy.

Plate XVII.

On heating, the combined points ARS1 and 2 appear at 717°; AR3 is absent. On cooling, AR3 appears to have become confused with AR2, resulting in a somewhat erratic evolution of heat ranging from 750° to 675°. AR1 appears at 661°, or 24° lower than its normal position in pure iron and carbon alloys.* The above results, as far as the appearance of the combined points ARS2 and 3 is concerned, are in direct opposition to the conclusion of Mr. Osmond, who found that the double point appeared at a higher temperature than in normal steel. The chemical composition of the steel No. 261, already referred to, is practically identical with that of the chrome alloy excepting the presence of chromium. On inspecting the normal cooling curve of 261 it will be seen that the maximum of AR3 is distinct at a temperature of 20° above AR2, therefore, according to the β iron theory, chromium should distinctly harden iron.

* In chrome alloys containing a considerable percentage of carbon AR1 appears at 700°, or 15° above the normal.

The Tungsten Alloy.

Plate XVII.

On heating, AR3 is absent, AR2 appears at 729°, and AR1 is not visible. On cooling, AR3 is faintly developed at 834°, or about 16° below its normal position. AR2 occurs at 739°, and AR1 at 590°, or 95° below its normal temperature.* Here again, the author's conclusion with reference to the intensity of AR3 in tungsten and iron alloys is in direct opposition to that of Mr. Osmond, who, however, argued deductively from an iron and tungsten alloy containing more than $\frac{1}{2}$ per cent. of manganese—hence his error.

The Aluminium Alloy.

Plate XVII.

Both on heating and cooling, only the point AR2 appears, the absorption and evolution of heat being much the same in intensity and position as those observed in the rolled iron. Aluminium evidently prevents the development of the point AR3, and the small carbon percentage 0.03 has failed to produce at AR1 any evolution of heat capable of registration. In a similar alloy, containing about 0.25 per cent. carbon, the point AR1 occurs on cooling at 691°, but on heating, above AR2 at 750°.

The Silicon Alloy.

Plate XVII.

This alloy, on heating, showed only an absorption of heat at AR2 at 732°, or about 5° below its position in nearly pure iron. On cooling AR3 is absent, AR2 appearing about 730°, or 13° below the normal temperature. AR1 appeared at 692° or 7° above its usual position. (These results confirm those obtained by Mr. Osmond.) In high silicon alloys also containing appreciable amounts of carbon, AR1 appears on heating far above AR2 at 770°, or 50° above its normal position.

* The point AR1 as developed in tungsten steels possesses peculiar properties independent of its very low position. This matter, however, will be more suitably dealt with in the research now proceeding on the influence of carbon on alloys of iron.

The Arsenic Alloy.

Plate XVII.

On both heating and cooling AR2 appears in its normal position. ARS1 and 3 are both absent. In arsenic steels, containing an appreciable percentage of carbon, AR1 appears at 706° on cooling, and at 748°, or 11° above AR2 on heating.

The Phosphorus Alloy.

Plate XVII.

Only the point AR2 was present either on heating or cooling. Its position on heating is at 709°, or 28° below the normal temperature. On cooling it appears at 718°, or 25° lower than in nearly pure iron. Mr. Osmond stated that the point AR2 was not developed in alloys of iron with phosphorus. In phosphorus steels containing a considerable amount of carbon, the point AR1 appears at 706° on cooling, but on heating at 760°, or about 51° above AR2. This phenomenon resembles the reaction taking place in carbon and iron alloys rich in silicon or aluminium or arsenic.

The Sulphur Alloy.

Plate XVI.

The vagaries of the critical points in iron containing varying amounts of sulphur and carbon have been described in the article on electrolytic iron. In the present alloy, on cooling evolutions of heat take place at about 942°, 865°, 805°, 742°, and 685°.

On heating, ARS1 and 2 seem in their normal positions, the most noticeable feature of the curve being a very decisive absorption of heat at 948°.

Mr. Osmond has complained that the author's recalescence investigations had not resulted in the discovery of any new points. This matter he has now rectified. He has, however, no intention of claiming the discovery of two new allotropic modifications, namely, Delta and Epsilon irons, but is rather inclined to attribute the two new evolutions of heat caused in iron by the

FIG. 1.
OF NORMAL ALLOYS, DIA' OF TEST PIECES 0.564 INCH.

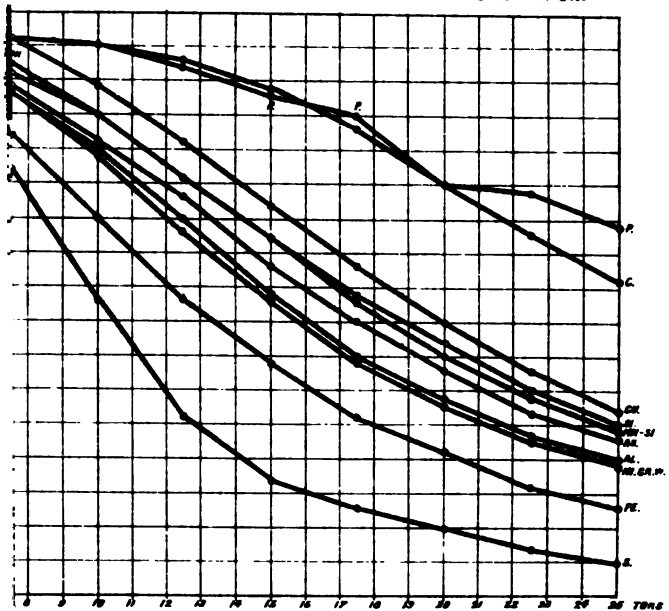


FIG. 2.
HARDENED ALLOYS, PIECES 0.564 INCH DIA'.

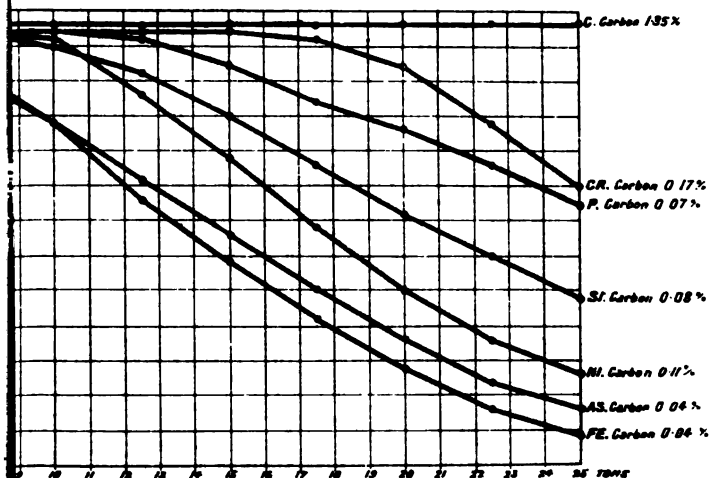


FIG. 5.

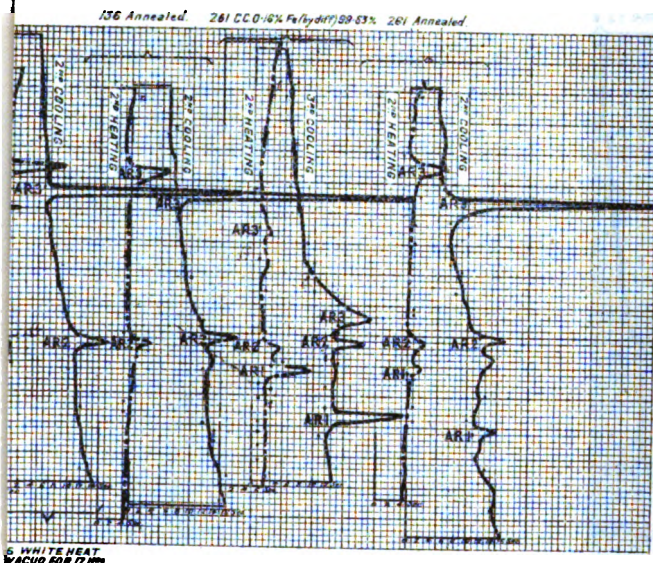


FIG. 6.

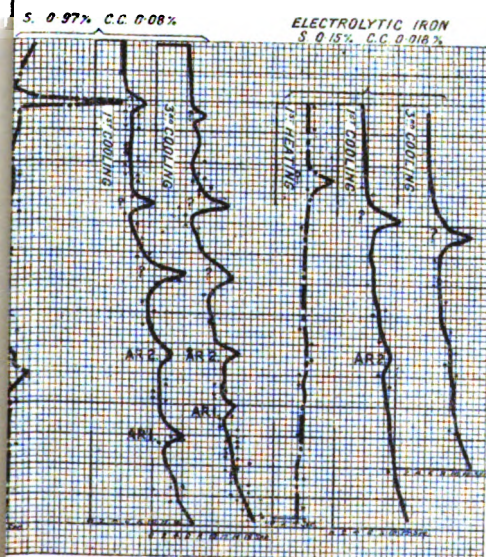


FIG. 7.

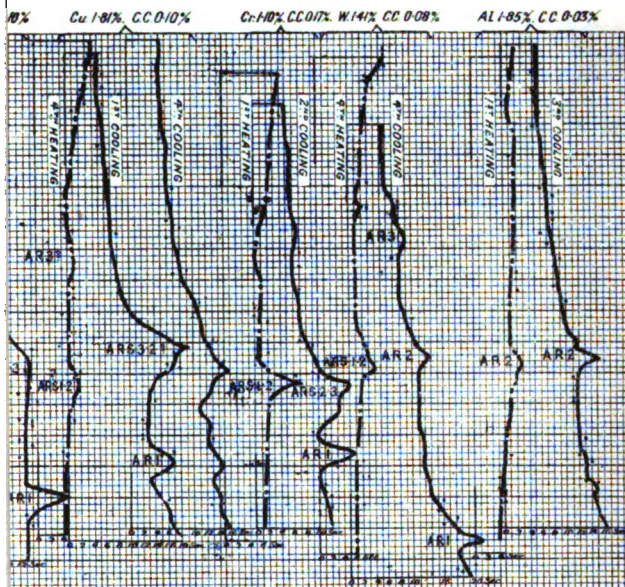
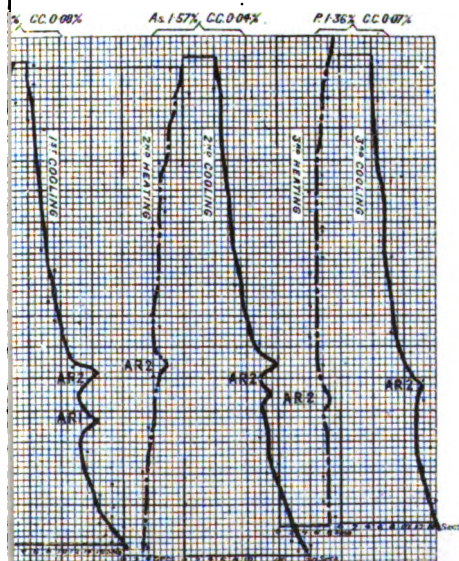


FIG. 8.



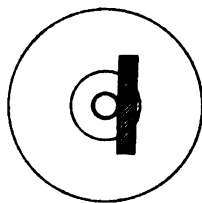
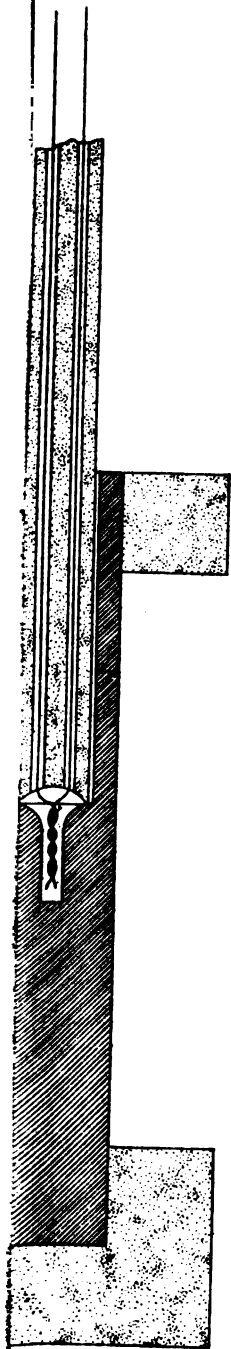
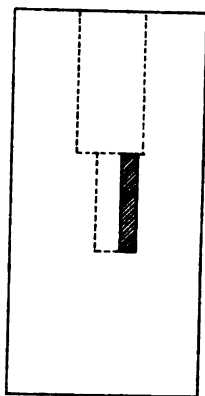


FIG. 4.



1871

1871

S C E

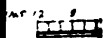


FIG. 3.
CHRONOGRAPHIC RECORDER

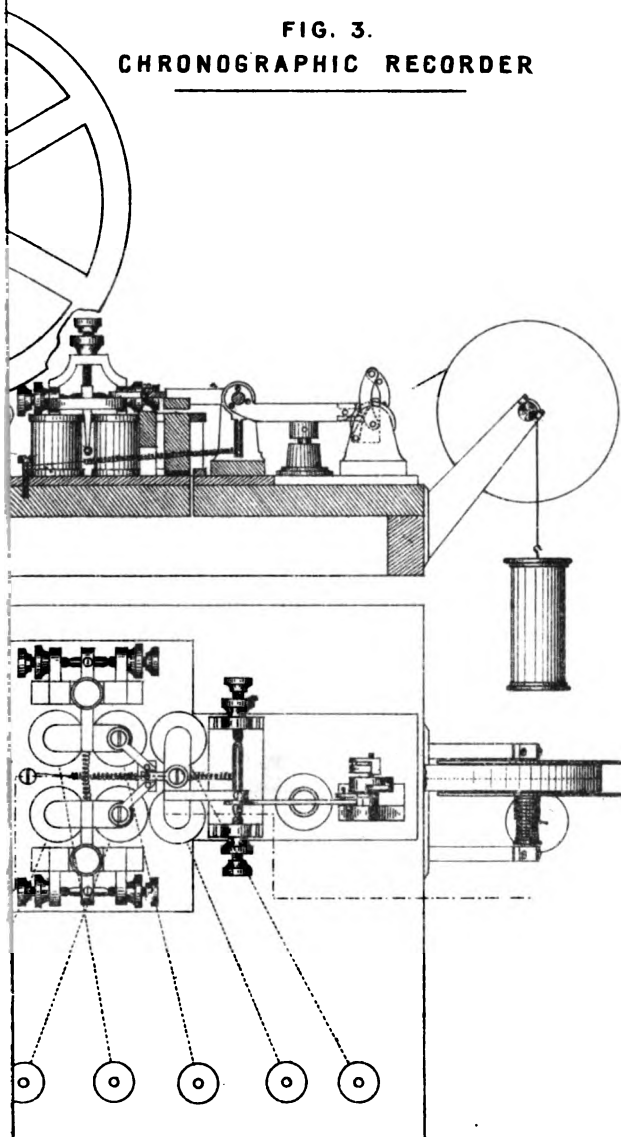


FIG. 5.

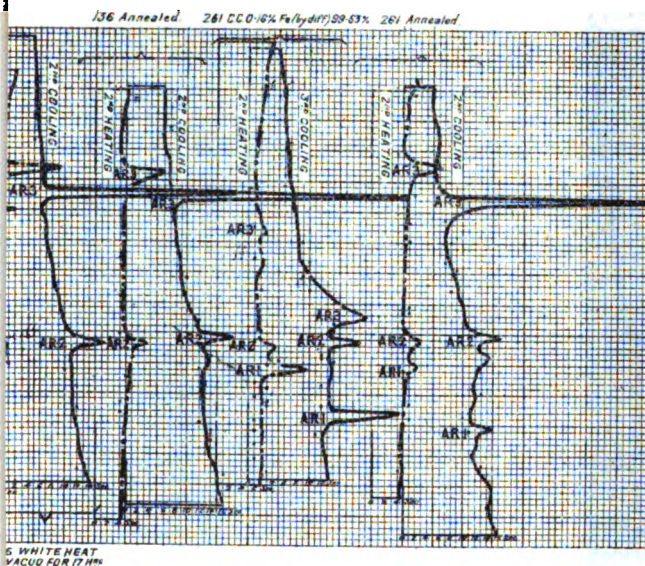


FIG. 6.

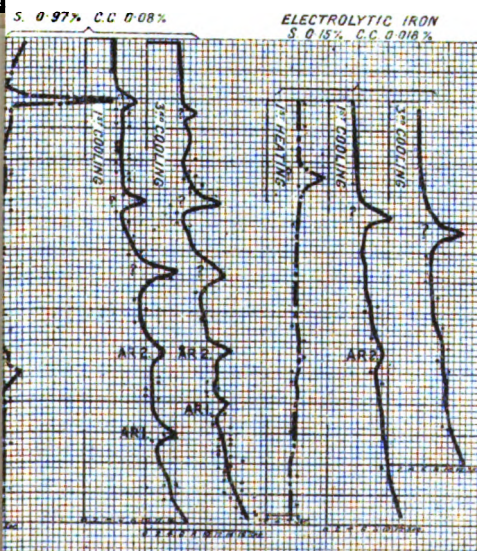


FIG. 7.

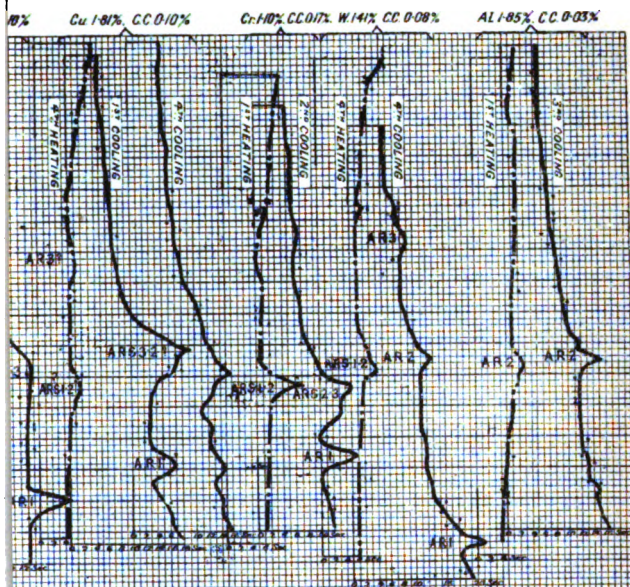
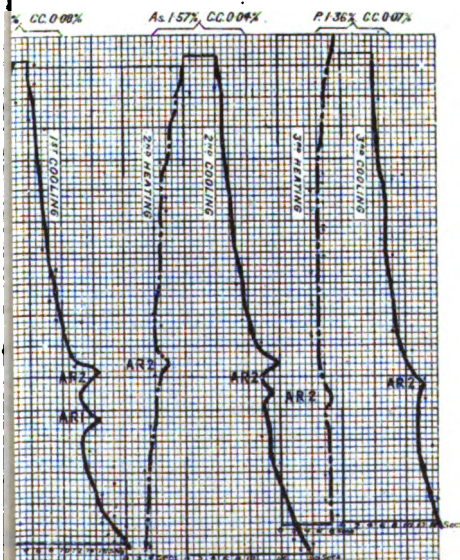


FIG. 8.



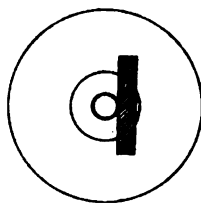
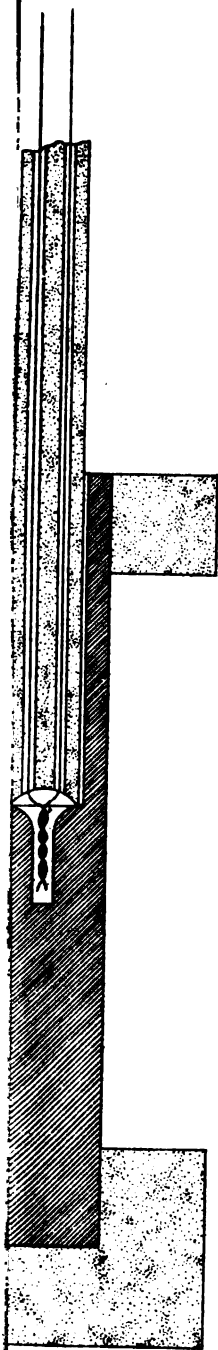
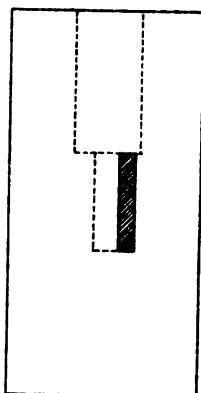


FIG. 4.



S C

S C E

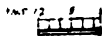


FIG. 3.
CHRONOGRAPHIC RECORDER

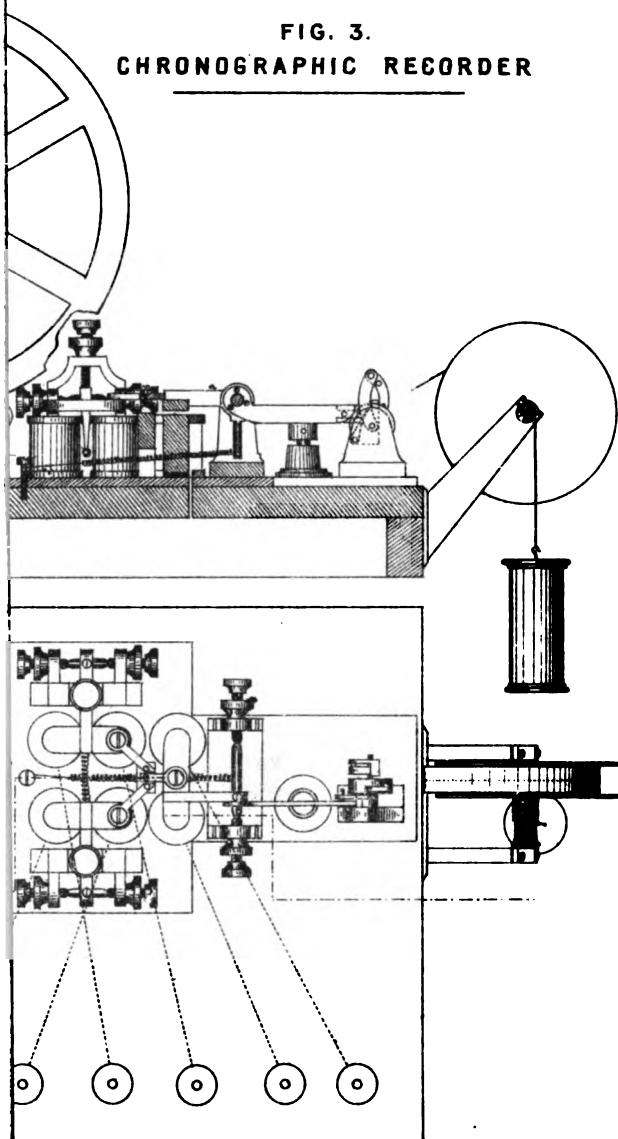
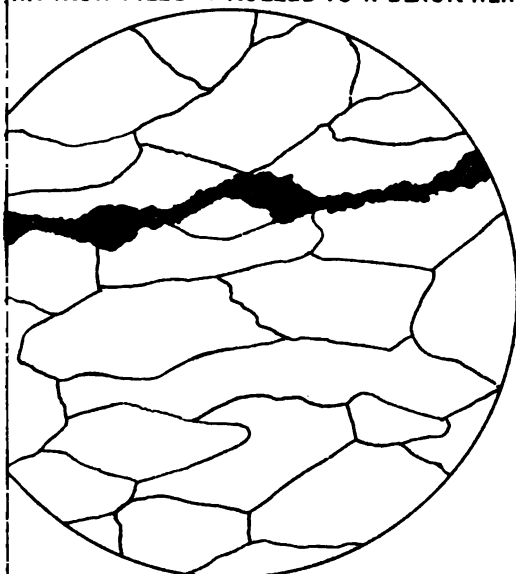
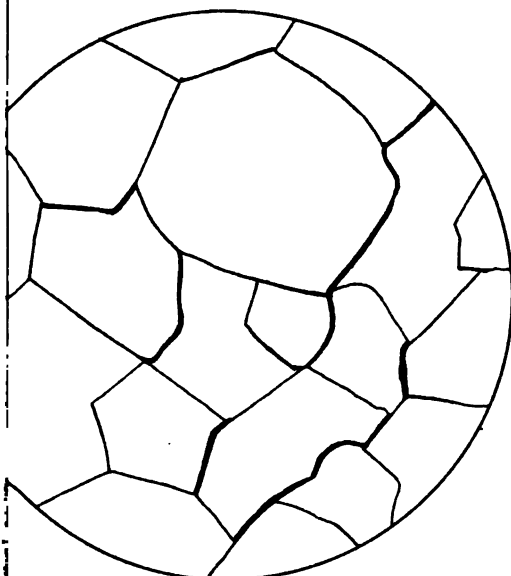


DIAGRAM A.

**LONGITUDINAL SECTIONS OF
AN IRON PILED & ROLLED TO A BLACK HEAT**

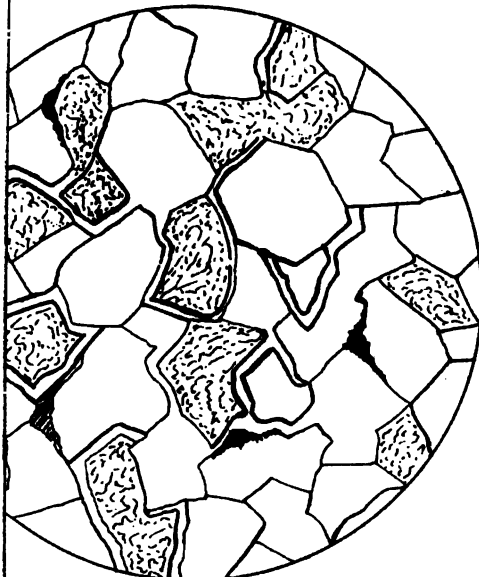


HEATED TO 650° C.

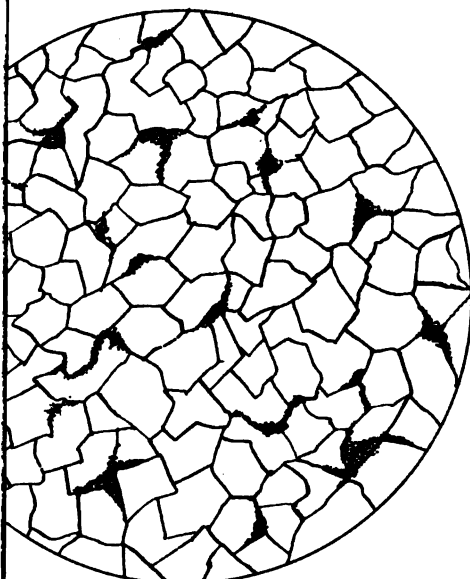


HEATED TO 850° C.

DIAGRAM B.

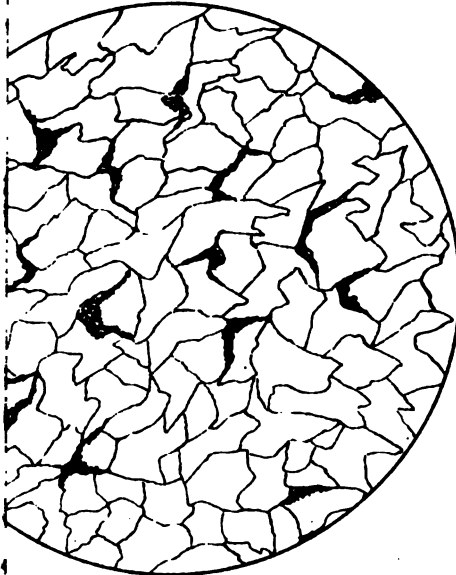


NORMAL IRON (ROLLED).

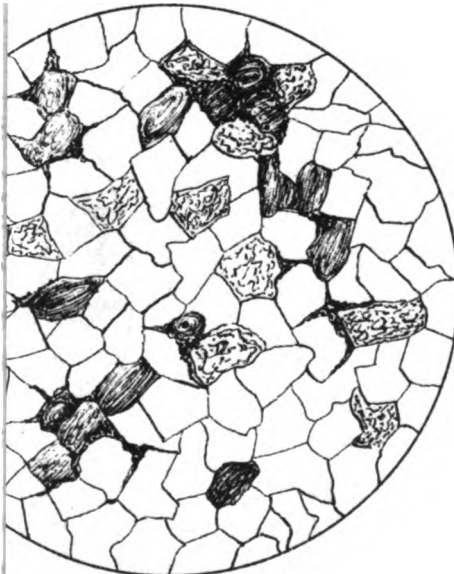


NICKEL CHROMIUM AND TUNGSTEN ALLOYS.

DIAGRAM C.

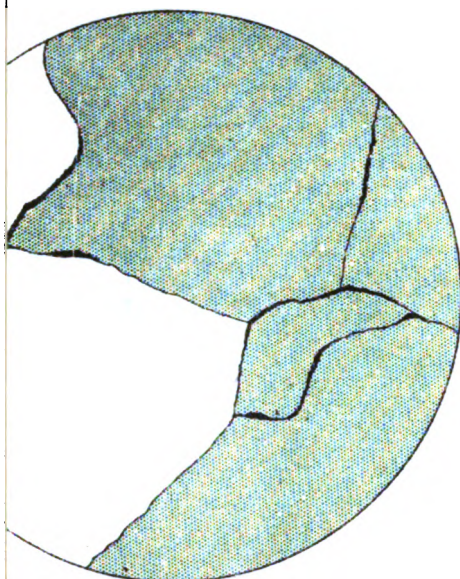


MANGANESE (AND SILICON) ALLOY.

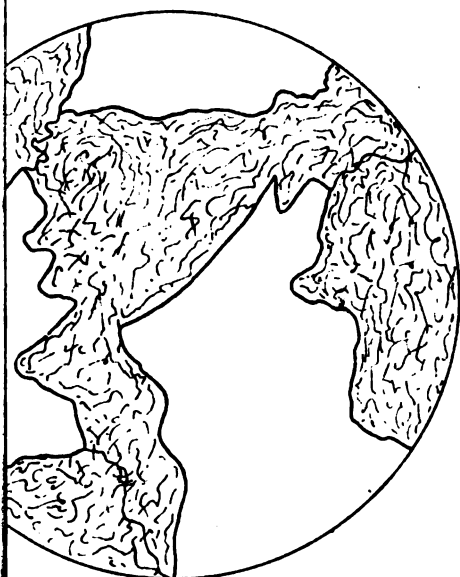


NORMAL COPPER ALLOY

DIAGRAM D.

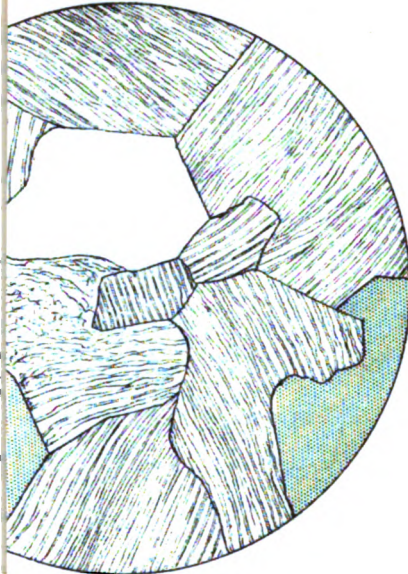


NORMAL ALUMINIUM ALLOY.

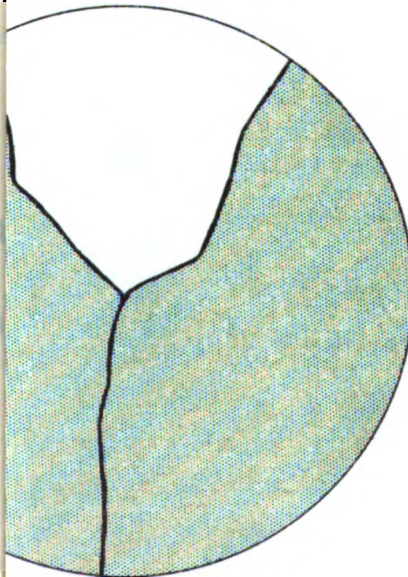


NORMAL SILICON ALLOY.

DIAGRAM E.

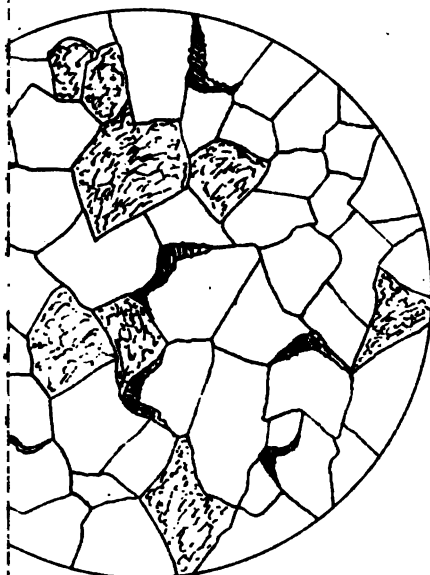


MAL ARSENIC ALLOY.

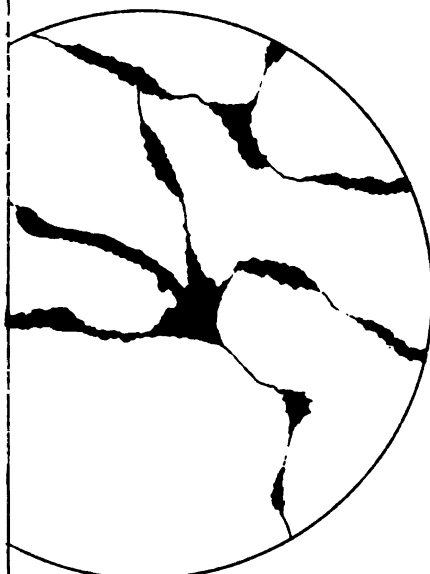


AL PHOSPHORUS ALLOY.

DIAGRAM F.



IRON (as cast).



SULPHUR ALLOY (as cast).

presence of a large amount of sulphur to the falling out of two sulphides of iron. Mr. Osmond came to the conclusion that the molecular action of sulphur was similar to that of phosphorus. This erroneous deduction, however, was based upon curves obtained from a single sample of red-short steel containing C. 0.48, Si. 0.08, S. 0.28, P. 0.16, Mn. 0.51.

The author has here much pleasure in placing upon record the invaluable assistance rendered to him in every stage of this research by Mr. Joseph Jefferson, Assoc.R.S.M. His skill and application in carrying out the details of the installation of the recalcence apparatus, and the patient and accurate manner in which he has recorded the pyrometric results, have proved him to be capable of taking a high rank in scientific research.

GENERAL VIEW OF RECALESCENCE RESULTS.

The results of the recalcence determinations may be generally stated thus, the statements having reference to iron containing about 0.1 per cent. of carbon and 1.5 per cent. of the alloying element. When AR1 has been absent from the curves, its position has been determined upon similar alloys containing about 0.25 per cent. of carbon.

AR1.

The position of AR1 on heating is distinctly raised by the presence of silicon, chromium, arsenic, phosphorus, sulphur, aluminium, tungsten, and manganese, and it is somewhat lowered by the presence of nickel.

On cooling, the point is lowered by the presence of tungsten, manganese, and nickel. It is, however, raised distinctly by silicon, arsenic, phosphorus, chromium; and slightly by aluminium and sulphur.

AR2.

AR2 is the only truly reversible point, and in nearly all the alloys is singularly constant in its position. Phosphorus has, however, lowered the temperature at which it usually occurs about 25°.

AR3.

The actions of elements upon AR3 may be summarised thus : Silicon, aluminium, phosphorus, and arsenic entirely eliminate this point. Tungsten much diminishes its intensity but does not greatly affect its position. Manganese, chromium, nickel, and copper lower it to or below AR2. The action of sulphur is dubious. The maxima of the critical points are shown in Table VI.

TABLE VI.—*Table of the Maxima of the Critical Points.*

(Degrees Centigrade.)

The letter *i* signifies that the point indicated has an unusual amplitude, rendering the maximum indeterminate.

The letter *a* means absent, but such absence may be only apparent, being really due to the spreading out of a minute evolution or absorption of heat over such a long range of rise or fall of temperature, that the registration of the thermal effect is beyond the delicacy of the instrument.

Alloy.	Carbon.	AR1.		AR2.*		AR3.	
		Heating.	Cooling.	Heating.	Cooling.	Heating.	Cooling.
	Per Cent.						
Iron . . .	0·04	<i>a.</i> (720°)	<i>a.</i> (682°)	737°	743°	867°	846°
Carbon . . .	1·35	713°	685°	...	...	...	...
Nickel . . .	0·11	702° (703°)	645° (649°)	733°	742°	808°	748°
Manganese . . .	0·10	722° (712°)	626° (643°)	722°	(<i>i</i>)	812°?	735°?
Copper † . . .	0·10	716°	654°	716°?	?	815°?	?
Chromium . . .	0·17	717° (754°)	661° (700°)	717°	?	<i>a.</i>	?
Tungsten . . .	0·08	<i>a.</i> (734°)	590° (580°)	729°	739°	<i>a.</i>	834°
Aluminium . . .	0·03	<i>a.</i> (750°)	<i>a.</i> (691°)	734°	737°	<i>a.</i>	<i>a.</i>
Silicon . . .	0·08	<i>a.</i> (770°)	692° (705°)	732°	730°	<i>a.</i>	<i>a.</i>
Arsenic . . .	0·04	<i>a.</i> (748°)	<i>a.</i> (706°)	737°	737°	<i>a.</i>	<i>a.</i>
Phosphorus . . .	0·07	<i>a.</i> (760°)	<i>a.</i> (706°)	709°	718°	<i>a.</i>	<i>a.</i>
Sulphur ‡ . . .	0·08	725° (726°)	670°? (691°)	737°?	742°	?	864°?

(Note.—The temperatures in brackets refer to the position of the points in alloys containing a considerable amount of carbon.)

* Mean amplitude of this point, 30° C.

† The positions of the points in the case of this alloy are somewhat doubtful owing to the complication of the curve by the dissociation or by the falling out of iron-copper alloys.

‡ This alloy presented distinct evolutions of heat on cooling at about 942° C. and 803° C., the position of the point first named falling somewhat lower with each successive heating. A decisive absorption of heat also took place during heating at 946° C. Whether the point appearing at 864° is identical with that observed in dead mild steel is dubious; AR3 may be the point next below (see remarks on sulphur alloys in comments on electrolytic iron).

GENERAL SUMMARY.

It now remains to concentrate into tabular form the evidence for and against the existence of β iron.

Original Premises upon which the β iron theory was founded.

1. That the point AR3 had been identified in a highly satisfactory manner with the appearance and disappearance of magnetism in nearly pure iron.

2. That the non-magnetic properties of Hadfield's manganese alloy formed experimental proof that iron was maintained in the hard and non-magnetic β form by the presence of manganese.

3. That the β iron change point occurs earliest on cooling in electrolytic iron, and is in that substance most individualised on account of the purity of the iron.

4. That Electrolytic iron (presumably chemically pure) presents the point AR3.

Results of Recent Researches upon the accuracy of the original Premises.

1. It is now generally admitted that the appearance and disappearance of magnetism coincides with the point AR2 which occurs about 100°C. below AR3.

2. The author understands that Mr. Hadfield will lay before the Institute the results of his recent researches upon this matter which, in the author's opinion, disprove the alleged β iron producing power of manganese.

3. It has been shown that in the present research the point AR3 was developed at the highest temperatures, in the greatest intensity, and was most individualised in the cases of mild steels containing from 0.06 to 0.16 per cent. C. In one instance, indeed, an actual rise in temperature was recorded in the last-named steel at AR3.

4. It has been shown that the preparation of a considerable mass of electrolytic iron, free from sulphur, is a matter of difficulty, and that only one abnormal experiment on iron free from carbon has been recorded without statement as to the amount of sulphur present. (A very important matter, inasmuch as it has been proved that this element develops at least two points additional to the three observed in mild steels.)

The two items of inquiry to obtain answers to which was the object of the foregoing investigations have therefore been replied to as follows:—

1. The experimental evidence has proved beyond doubt that the ultimate physical influence of elements on iron is not in any way governed by the periodic law. If any such influence exists at all, the molecular action is so feeble that the interposition of other causes, viz., individual properties of compounds, and crystalline effects has converted the law into a series of exceptions.

2. That in the alloys dealt with no element except carbon has (*per se*) the power of conferring upon quenched iron the property of abrasion hardness to any extent worthy of consideration. Whether the adamantine hardness of quenched high carbon steel is due to the individual properties of an extremely attenuated carbide of iron or to an allotropic change produced in the iron itself, by the presence of dissolved carbon there is no evidence to show, nor is the matter of much practical importance, since such hardening power is possessed by carbon alone.

Many of the indications furnished by the experimental results herein detailed act as finger-posts to the directions in which profitable researches on iron and steel may be pursued, viz.:—

1. An investigation of the inter-crystalline joints or spaces.

2. Experiments upon the action of elements in producing double carbides with iron. Evidence has already been obtained of the existence of double carbides of manganese, chromium, nickel, and tungsten.

3. An examination into the influence of silicon on the crystalline structure of steel.

4. The remarkable mechanical effects produced by sulphur and phosphorus require immediate attention with reference to the dangerous influence of liquated masses of sulphides and phosphides in the structure of very large and consequently slowly cooled ingots.

In conclusion, the author has to acknowledge in grateful terms the cordial co-operation of Professor Ripper, Principal of the Sheffield Technical School, and his staff in the Engineering Department, more particularly mentioning the name of Mr. G. C. Gulliver, Chief Instructor in the Machine Shop.

DISCUSSION

ON PROFESSOR J. O. ARNOLD'S PAPER.

THE following contribution to the discussion has been received from Mr. Osmond :—

I had the honour, as Professor Arnold has pointed out, to present to the Iron and Steel Institute, in 1890, a paper in which I recognised, during the cooling of steel, three evolutions of heat or critical points, AR1, AR2, AR3. These three points are united in highly carburised steel, and may be identified with Chernoff's point A; but they are distinct in "mild steel." What do each of them signify?

As regards the point AR1 there are no difficulties; it is simply a question of the formation of carbide of iron Fe_3C isolated first by Dr. Müller, and subsequently, with the aid of different methods, by Sir F. Abel and by myself in conjunction with Mr. Werth. As regards the other points, I attributed them to iron itself, but the facts then known did not enable me to decide whether AR2 and AR3 were due to the existence of two distinct molecular transformations of iron, or to two portions which were sometimes separated and sometimes united, of a single molecular change.

The second hypothesis appeared to me to be the most *probable*, especially because an experiment of Dr. Hopkinson seemed to identify the acquisition of the magnetic property in iron with the point AR3 in the most satisfactory manner. I was careful, however, to state distinctly that the choice between the two hypotheses was only provisional, a prudent reserve, as the sequel showed. Some months later I myself determined the critical points and the full appearance of magnetism on the same samples and during the same operation of cooling, and I found that this last phenomenon regularly corresponded, not to AR3, but to AR2. An important constant was thus obtained. Being anxious that it should be verified by others, I wrote to Dr. Hopkinson, who had on this question rights of priority, and he replied (18th March 1891) that the removal of his laboratory would not permit him to conduct experiments for some time, and he urged me with very great courtesy to

publish my own results without delay. I then turned to Professor Roberts-Austen, who undertook with Mr. H. Tomlinson to make certain experiments, the results of which are still unpublished, but generally they confirm my own. In a report "*Sur la Méthode du Refroidissement*," presented to the *Commission des Méthodes d'essai des Matériaux de Construction*, I defined, for the first time in a printed document, the distinction between the points AR3 and AR2. This report is dated 28th of January 1892, and consequently owes absolutely nothing to Professor Arnold.

The points AR2 and AR3 being thus distinctly separated, it only remains to seek the cause to which they are respectively due.

1. The appearance of magnetism, a characteristic property of iron, proves that the point AR2 is not due to a chemical reaction but to a physical change in the iron itself. It represents an allotropic change. Professor Arnold, while admitting that his proofs are not conclusive, maintains that the point AR2 marks the passage of iron from the *crystalline* to the *plastic* state. I, for my part, see no objection to this; far from it. It is true that the *development* of crystallisation, or in other words the point B of Chernoff,* an author whom Professor Arnold seldom quotes, does only become distinctly marked at a much higher temperature, say between 900° and 1000°, in the case of very mild steel. But as this point B does not correspond to any sensible evolution of heat, it appears certain that we must look deeper for the origin of crystallisation; we must in fact look to the point AR3 or AR2. I was myself inclined, in 1888,† to place it at AR2, but at that period I had not separated the point AR3 from AR2, and the question must be reconsidered. I am, however, astonished that Professor Arnold, in claiming as his own an explanation which I offered many years before he did, does not see that this explanation, if it is accurate, affords an additional proof of the existence of allotropic change. That we are not in agreement as to this, evidently shows that we do not use the word in the same sense, and that there is in Sheffield a definition of allotropy which differs entirely from that which is to be found in classical chemical treatises.

* The notation A does not mean "arrest"; it was introduced by Chernoff, and it appeared to me to be equitable to retain it.

† "*Études Métallurgiques*," *Annales des Mines*, Series 8, vol. xiv. p. 68.

2. As regards AR3, in 1891 * Professor Arnold considered the point AR3 "to be very insignificant," in 1893 † he attributed it to the presence of hydrogen, now he considers that the same point is due partly to the presence of sulphur and partly to that of a subcarbide.

It is perfectly possible that the electrolytic iron employed by Professor Arnold contains much sulphur, and that this impurity produces, on its own account, two evolutions of heat, one of which is blended with AR3. But the electro-iron which I employed contained less than 0.002 per cent. of sulphur. As regards the existence of a sub-carbide of iron I say nothing *à priori*, for the last word has not been said as to the modes of existence of carbon in iron. I only point out that the point AR3 coincides—

1st. With a variation of volume (Le Chatelier). ‡

2nd. With the angular point in the curve in which electrical resistance and temperature are co-ordinates (Le Chatelier). §

3rd. With another angular point in the curve, which represents the thermo-electric property of iron (Osmond). ||

4th. With a perturbation in the feeble magnetic power of iron which continues above at AR2 (Curie). ¶

We are then in presence of numerous groups of simultaneous phenomena, all of which have been *studied with the aid of the same pyrometer*, and in this group of phenomena, AR1 (the carbon change) has no influence. These phenomena indicate the allotropic transformation of iron with a degree of certainty such as chemistry gives us few examples of. If a slight doubt still existed as to the occurrence of this change, owing to the fact that we have not as yet seen chemically pure iron, this doubt is diminished and not increased by Professor Arnold's own experiments, because he finds that the point AR3 is well developed in one of his test-pieces, which is less carburised (0.04 of carbon) than the least carburised of those I employed. I cannot, therefore, see the slightest reason for modifying my opinion as to the signi-

* *Engineering*, Nov. 6, 1891.

† *Proceedings of the Institution of Mechanical Engineers*, 1893, p. 158.

‡ *Comptes Rendus de l'Académie des Sciences*, vol. cviii. p. 1096.

§ *Ibid.*, vol. cx. p. 283.

|| *Transformations du Fer et du Carbone*, p. 64 and plate 8.

¶ *Comptes Rendus de l'Académie des Sciences*, vol. cxviii. 1894, p. 859.

fication of the points AR2 and AR3. This opinion, moreover, is not held by me alone; it has been contested, so far as I know, neither by physicists nor by chemists. As Dr. Gore* says, "every substance becomes more or less a different substance at every different temperature;" and Professor Norman Lockyer, does not he aid us by pointing to the progressive depolymerisation which bodies undergo as the temperature is raised? Iron, therefore, only presents a special case of a general law.

All that is changed since 1890 is that points AR2 and AR3 are seen to be definitely separated, and that instead of a single allotropic modification of iron there are at least two;† in other words, iron is in the α state below AR2, is in the β state between AR2 and AR3, and in the γ state above AR3.

But if it is shown that iron is changed at certain critical temperatures, is it equally clear that the allotropic forms can be retained at the ordinary temperature? The question has made less advance in this direction. Every allotropic form is naturally unstable beyond the limits of temperature within which it is spontaneously produced, and only becomes stable by the intervention of external forces. In the same way a body placed on an inclined plane always tends to descend, and does so or not according to the relative values of the angle of inclination of the plane and the coefficient of friction.

Among the causes which are the analogues of friction in maintaining allotropic forms outside their normal state of equilibrium may be reckoned pressure, and the presence of foreign matter. In the case of iron notably, it is experimentally proved that carbon takes first rank;‡ then manganese and nickel lower the critical points during cooling, and render the β and γ varieties of iron stable within a range of temperature in which they are not naturally so. Experiment also proves that this range may even be extended below the ordinary temperature, because alloys

* *Journal of the Iron and Steel Institute*, 1890, No. I., p. 78.

† I say "at least," because we may have to include the point detected by Dr. Ball, the meaning of which is uncertain, but the existence of which appears to be assured.

‡ I am often reproached that I depreciate and, so to say, insult carbon. The truth appears to me that I have given a plausible explanation of the part played by this element, while my adversaries have offered none. But whether carbon is employed in setting up a kind of friction which maintains iron in the β or the γ state, or whether it has quite a different junction, it is certain that we have need of it.

are known of iron with manganese and with nickel which are not magnetic, and consequently contain iron in either the β or γ form.

At this point theory begins. It must be well understood that this theory may need revision in taking into account the existence of γ iron. It is a piece of work which I could undertake at once, but I prefer to wait until I have gathered sufficient facts to reduce part of the hypothesis and to suppress it if possible.

Foreign elements which tend to maintain cooled iron in one or other of its allotropic forms have all an atomic volume smaller than that of iron, and this fact has led Professor Roberts-Austen and myself to extend to iron the relation which my distinguished friend has found to hold good in the case of gold. Professor Arnold of course combats this view even while supporting it by his own experiments. If, in fact, we for the present set aside the case of boron and that of sulphur, the effects of which are not sufficiently known, it is proved—

1st. That hydrogen, carbon, manganese, nickel, and copper lower AR_3 .

2nd. That carbon, manganese, and nickel lower the double point $AR_{3.2}$ when they are present in sufficient quantity.

3rd. That tungsten, aluminium, silicon, arsenic, and phosphorus tend, as the quantity in which they are present increases, to obliterate AR_3 without modifying its position.

All these facts are accepted by Professor Arnold now that he has verified them, and some of them are even borrowed from him; all the facts are in accord with the law of atomic volumes, and verify the principle* on which it rests. This law, of which I can speak quite freely, as I did not frame it myself, possesses great importance. As was observed in an excellent unsigned article published in *Industries*, May 23, 1890, it establishes a new correlation between allotropic transformations and the melting and boiling points, which are also lowered by the addition of foreign elements. Moreover, as it follows from an experiment by Mallard and Le Chatelier on iodide of silver, and another experiment by Roberts-Austen on steel, that pressure

* Mr. Arnold makes objections as regards chromium, but the only alloy to which he refers contains 0.17 per cent. of carbon, and I see nothing at present to alter in the conclusions I drew from a detailed examination of a large series.

alone also lowers the temperature at which allotropic changes occur, we are led to the conception that foreign bodies may exert in a *solid* alloy osmotic pressure, provided that their atoms are sufficiently small to retain liberty of movement in intermolecular spaces.

Professor Arnold has certainly the right to disclaim interest in such scientific considerations, but he should not complain if others are interested in them, following the example of the Royal Society, which had encouraged with its highest recognition the work of Raoult, of Van't Hoff, and of Le Bel.

It must not be forgotten, however, that the law of Roberts-Austen, like the cryoscopic law, is a limited law. It assumes that the foreign body preserves in solution its natural and individual state, and does not form chemical compounds with the solvent. The starting-point at which these compounds cease to intervene is very variable. In alloying iron with such high proportions of these bodies as 1.50 per cent., Professor Arnold often exceeds these limits, as is abundantly proved by his own investigations on the structure of his alloys, especially in the case of phosphorus, of arsenic, and of sulphur. He therefore seeks, under these conditions, a verification where one was impossible.

Notwithstanding these restrictions, the consideration of atomic volumes has none the less a real practical interest. I wish no better proof of this than the opinion of Mr. Hadfield. In the discussion which followed the reading of the first report of Professor Roberts-Austen to the Alloys Research Committee, Mr. Hadfield proposed a classification which I place in juxtaposition, in the following table, with the classification of the action of certain elements in the order of their atomic volumes.

<i>In Hadfield's Classification.</i>	<i>Classification according to the Law of Atomic Volumes.</i>
Carbon	Carbon 3.6
{ Nickel	Nickel 6.7
{ Manganese	Manganese 6.9
{ Chromium	Copper 7.1
{ Tungsten	Chromium 7.7
{ Aluminium	Tungsten 9.6
{ Silicon	Aluminium 10.5
{ Sulphur	Silicon 11.2
{ Phosphorus	Arsenic 13.2
{ Arsenic	Phosphorus 13.5
{ Copper	Sulphur 15.7

It is evident that the groups are exactly the same in the two columns, except in the case of copper, but it is known also that if it sometimes gives rise, under conditions which are but little understood, to defects which assimilate its action to that of sulphur, it can nevertheless be employed as an aid analogous to nickel in materials which demand the highest qualities.

Does all this show that it is sufficient to know the proportion of a foreign element present in steel, and the atomic volume of this element, to immediately foretell the exact properties the alloy will possess? Neither Professor Roberts-Austen nor I have ever said or thought that such would be the case. For my part I so little dispute the importance of structure of joints or of crystallisation, that I expressly sent to the meeting at Chicago a communication in which I called attention to this point.

The mechanical properties of a metal are a complex resultant of the molecular structure, of the structure which can be rendered visible by the microscope, and of residual tensions. The volume of the atom of the added element only influences the first of these factors (the molecular structure), and must doubtless often be masked by the others. Professor Arnold's mechanical tests are perfectly useless as a means of confirming or denying the existence of this influence of the volume of the atom: the general results were already known.

THE RESULTS OF HEAT TREATMENT ON MANGANESE STEEL AND THEIR BEARING UPON CARBON STEEL

BY R. A. HADFIELD (MEMBER OF COUNCIL).

THE author has recently conducted some experiments upon the peculiar behaviour of manganese steel when submitted to certain kinds of heat treatment. As the results indirectly bear upon the research work which Professor Arnold has placed before this Institute, it was thought that a description of them might be of special interest at the present time.

The author, owing to his connection with the Committee of Management at the Sheffield Technical School, has for some time past been brought into contact with the excellent research work being done by Professor Arnold, and would take this opportunity of expressing his satisfaction that so important a contribution has been secured for the *Journal of the Iron and Steel Institute*. Work of this kind must naturally submit to criticism of a searching nature, but in any case the author ventures to think that, with the admirable system of correlation adopted by Professor Arnold, our knowledge of the subjects dealt with will be much extended.

Owing to the complex nature of alloys of iron, it is now being conclusively proved that, in order to accurately judge and explain their various characteristics, it is necessary to have not only a chemical analysis, or this accompanied by a mechanical test of the material, but also the micro-structure on the lines of research initiated many years ago by Dr. Sorby, of Sheffield, and finally a report of the behaviour under thermal treatment. As regards the latter subject we are indebted to Mr. Osmond, whose work has been so excellently continued in this country by Professor Roberts-Austen, and now further developed by Professor Arnold.

Correlation of experimental work has already produced fruit by showing how important it is to develop analytical methods in a more complete and searching manner than in the past. The

important work in this field already inaugurated by one of our past Presidents, Sir Frederick Abel, and recently carried still further by Professor Ledebur, cannot be too highly valued. To the author it seems that it is in this direction we shall now have to look for further light, one which has become more clearly apparent by the research work of Mr. Osmond and Professor Roberts-Austen.

The author knows that Professor Arnold has bestowed much labour and pains in the preparation of his paper, and it will remain for those who have advanced theories on different lines to prove whether, in view of the facts now presented, previous conclusions can be sustained. For example, it would seem that the theory as to the existence of a β , or hard form of iron, will now require further very careful consideration, and as to whether it can be entertained seeing the strong evidence to the contrary gradually being adduced by many workers.

The experiments that will be described in this paper also seem to point to the fact, that the hardening of steel must be explained in some other manner than has lately been so prominently put forward. Attractive as may be the allotropic theory as to the existence of a β , or hard form of iron, it would seem that the facts now being brought together by various investigators confirm the objections urged against it by authorities such as Ledebur, A. le Chatelier, H. le Chatelier, Howe, Stead, Arnold, Müller, and others.

With reference to the experiments mentioned in this paper, the author need hardly remind members of this Institute, that alloys of iron and manganese, or rather, iron, carbon, and manganese, known as ferro-manganese, rich spiegel, and the new metal manganese steel, have been found to be practically non-magnetic.

David Mushet noticed this curious fact so far back as 1830, in connection with a rich spiegeleisen or ferro-manganese he had produced; but as regards a malleable manganese steel, or alloy, this was first described in papers read before this Institute and before the Institution of Civil Engineers on "Manganese Steel" in 1888. The author found that as the percentage of manganese increased in the alloy the magnetic susceptibility greatly diminished. An alloy containing 11 per cent. of manganese was in bulk apparently non-magnetic, though considerably under mag-

netic influence when reduced to a fine state of division, such as drillings and poundings. On further increasing the manganese to 13 per cent. the material was found to be practically non-magnetic, not only in bulk but even in a fine state of division. As Dr. Hopkinson said, the magnetic properties of the metal iron were practically annihilated.

Special attention is called to the remarkable difference in the magnetic properties of this material by the further comparatively small increase of manganese, namely, about 2 per cent. Why this should cause such a marked change it is difficult to understand. The author believes it will be eventually found that this is considerably due to a particular kind of carbide of manganese, or carbides of manganese and iron, whose properties vary according to the thermal treatment; he hopes to have important proof of this before long.

With reference to the magnetic qualities of manganese steel, Professor Ewing's interesting remarks, during the discussion on the author's "Manganese Steel" paper,* show that the magnetic susceptibility of this material "is only 0.036, whereas in soft iron it touched a maximum of 280. In other words, a piece of soft wrought iron, when exposed to a magnetic force of moderate amount, was something like 8000 times more susceptible to magnetism than manganese steel." But as he also pointed out at the same time, and his remarks have not, perhaps, been borne in mind sufficiently, with 10,000 C.G.S. units the intensity of magnetisation on a sample of this manganese steel was nearly 400 C.G.S. units, or as high as that commonly found in permanently magnetised bars of magnet steel. He said, "Manganese steel could not therefore be spoken of as destitute, or nearly destitute, of magnetic qualities. What was remarkable and important was the extreme difficulty with which it was magnetised, though of course no magnetising force which the metal was likely to be subjected to in its practical applications would produce more than the most infinitesimal degree of magnetisation."

Naturally enough it may be asked—Is this state of non-magnetisability of manganese steel permanent? Seeing the large amount of iron present in the alloy, it might be well

* *Minutes of Proceedings of the Institution of Civil Engineers*, vol. xciii. p. 114.

imagined that such a state was only an artificial one. As will be seen from the experiments described, this is to some extent correct. At first sight the further facts noticed respecting the behaviour of this peculiar material only seemed to add fresh difficulties to a satisfactory explanation. But when carefully considering all the points, they may result in explaining several anomalies not understood.

By the results of these further experiments it has been found that, by certain heat treatment hereafter described, manganese steel—a practically non-magnetic material—can be rendered considerably magnetic, yet by further treating the same material the previously non-magnetic qualities can be restored at will. Dr. Fleming, an eminent authority on electrical matters, in some correspondence with the author on these results, has been good enough to say “that the facts now noticed concerning this material are so important as to be full of promise for valuable additions to our knowledge of magnetism.”

Now, manganese steel, as ordinarily produced, being non-magnetic, has been quoted as a proof of the existence of one or even more forms of iron than that we really know does exist at ordinary temperatures. It is claimed that in iron alloys there is a β , or hard form of iron, which exists above a temperature of about 740° C. (critical point Ar₂). The critical point known as Ar₃, occurring at about 860° C., has been principally quoted as proving that there is an entire revolution in the atoms of the soft metal iron, that they then become hard, and that this is further supported by a loss of magnetic properties in hard iron or steel, a change which occurs at or about what is known as the critical point Ar₂ (740° C.). In a paper on “The Critical Points of Iron and Steel,” * Ar₂ is described “as merely probably being a retarded end of Ar₃.” Above Ar₃ (860° C.) an allotropic β iron originates, below Ar₂ only α , or soft iron, is formed. Between Ar₂ and Ar₃, when these are distinct from each other, then there is a mixture of α and β forms. But Professor Arnold proves, in his research work, that Ar₃ is irregular and variable, and that even it may be ascribed to a carbide change, or to some impurity present. For example, in electrolytic iron, believed to be absolutely pure, there

* *Journal of the Iron and Steel Institute*, 1890, No. I. p. 46.

was found a considerable percentage of sulphur which caused the critical point noticed during cooling.

As manganese steel is non-magnetic at ordinary temperatures, it has been claimed that the manganese present has a power of retaining the supposititious, or hard β iron, held to exist above AR₃, or 860° C., in the same state, even when the alloy is cooled down to atmospheric temperature, and therefore this is the reason why manganese steel is non-magnetic. The author, in his original paper to this Institute, was careful to point out that manganese steel, except when the manganese exceeded 12 per cent., could not be termed non-magnetic. It is well to bear this clearly in mind in order to avoid confusion. Its hardness, too, never approaches that of hardened carbon steel.

The author willingly confesses that this theory as to the existence of a hard form of iron seems an attractive one. In his own paper (Part II. on "Manganese Steel") presented to the Institution of Civil Engineers in 1888, and before the β iron theory had been put forward so prominently—in fact, at that time he was unaware of this—he suggested that, owing to the difficulties of offering any satisfactory explanation as to the many curious properties of manganese steel, properties which have puzzled most of the leading scientists, whether electrical, physical, or metallurgical, it did seem as if it would be necessary to fall back on some explanation of this kind, and that iron might possibly have some other form than that hitherto known—in other words, that it might possess allotropic modifications, one of which was a hard form. But as further facts came to light, he could not find any clear proof of this assumption. In view of the information given in this paper it will be seen that, at any rate as regards the bearing of the β , or hard form, stated to exist in manganese steel, that this does not seem to be now possible, for the same material, and in each case possessing practically the same composition, can be made to become magnetic or non-magnetic *at will*.

The author feels now strongly convinced that it is in some other direction than allotropic modifications of iron, or, at any rate, as regards a hard or β form, that we shall have to look in order to obtain a satisfactory explanation of the peculiar properties noticed, whether in manganese steel, or in quenched carbon

steel. The true one will, he believes, be found in accurately understanding and determining the properties of the various carbides of iron and manganese formed, whether in steels known as carbon steel, or other iron alloys, or in such a case as the triple alloy known as manganese steel, a combination of carbides of iron and carbides of manganese. Both carbon steel, if rapidly cooled, and manganese steel, whether cooled in water, or normally, show no recalescence or other critical points. To the author it would seem that here is another strong proof that the cause in either case is the formation of a particular carbide or carbides, probably of much more complex nature than hitherto imagined—in other words, that the hardness of either manganese steel or carbon steel, though the former never possesses the same intense hardness as quenched carbon steel, are chiefly produced by similar causes, that is, by similar combinations.

Mr. Arthur Wingham very clearly pointed out in the discussion on the paper by Dr. Ball, "On the Changes produced by Thermal Treatment of Iron,"* if there was a β form of iron in hardened carbon steel, surely the product ought to be non-magnetic, which is not the case. This inconsistency in the β iron theory, the author believes, has not been satisfactorily met. The following were Mr. Wingham's words: "There was one point in the paper, however, which seemed to savour of inconsistency. Mr. Osmond concluded that hardened steel owed its properties principally to the presence of β iron." Further on he stated, "that β iron above 860° C. was not magnetic, also that manganese steels, from the fact that they do not exhibit recalescence, and that, therefore, the iron in them was in the β compound, should be, and had been known to be, non-magnetic. How was the permanent magnetism of hard steel to be recognised with these facts? Apparently hardened steel must contain some α iron." Any one examining a quenched piece of hardened carbon steel in small section could certainly not find any α , or soft iron, present, and if not present why is the material magnetic?

Hardness seems to be quite independent of magnetic characteristics, as *very hard* (water-quenched) carbon steel is magnetic, whilst hard manganese steel is non-magnetic, or, as we shall

* *Journal of the Iron and Steel Institute*, 1891, No. I. p. 103.

see later, can be made to become considerably magnetic, and again non-magnetic, as may be desired by the operator. If the presence or absence of these properties can be shown to be independent of the physical quality known as hardness, surely it will not now be possible to claim that manganese steel is proof of the existence of a non-magnetic β , or hard iron. Further, if β iron can be made magnetic or non-magnetic at will, and of practically the same hardness in each condition, as in the case of the samples quoted, will it not be inconsistent to say that the non-magnetic state of iron heated above 740° C. is due to the existence of atoms of β , or hard iron, retained in that form even when cooled down.*

If our chemical knowledge of the various carbides of iron and manganese were in a sufficiently advanced stage, we should probably find that the peculiar characteristics of hard carbon steel, or manganese steel, are chiefly dependent upon the formation of particular kinds of carbides. Hence the importance of pushing forward this side of the investigation and research work.

Professor Arnold, in the experiments he has made, has clearly proved that even the Ar3 change is largely dependent upon the particular carbide existing in the sample, or even upon other causes hitherto unsuspected. But notwithstanding the laborious analytical research work which he is now placing before the Chemical Society,† in a joint paper by himself and Mr. W. Read, as well as that of Professor Ledebur, we are still unacquainted with the exact natures of the various carbides present in steel. Sir F. Abel placed before the Institution of Mechanical Engineers a full report on some of the aspects of this question.

Why should not our Institute offer some prize for papers, or appoint a committee to report on the best methods of determining

* During the discussion on the address by Dr. Hopkinson on "Magnetism" to the Electrical Engineers, 1890, Professor Ayrton stated, "that the magnetic quality of iron lost at a red heat is partially *regained* at a white heat." He pointed out that this had also been noticed by Dr. Wormell ten years previously. Professor Ayrton stated, that some of his repetition experiments did not confirm this as fully as he expected. It would be interesting if this point were definitely decided, as it is an important one.

† It is unfortunate that this paper on "The Chemical Examination of Carbides in Steel" does not come to us, so as to make the whole correlation complete. Perhaps some arrangement could be come to with the Society in question on this point, so that we might have the paper printed in full amongst our Proceedings.

carbon in its different combinations. In Germany this matter has been recently vigorously taken up, with the result that Professor Ledebur's valuable work, "On the Determination of Carbon in Iron," obtained the award of the *Verein für Beförderung des Gewerbflusses*, Berlin. A long memoir by Dr. Göttig, "On the Examination into the Accuracy of Methods used for Determining Carbon in Iron," was presented at the same time. This also received special recognition by the same Society. With true German thoroughness a careful examination into nearly seventy different methods is given. Such painstaking work by the two scientists named, shows that our German friends recognise the importance of this subject, and also of encouraging scientific research work. Those desirous of referring to the subject will find abstracts in the *Minutes of Proceedings of the Institution of Civil Engineers*, and in this volume. The originals appeared in *Verhandlungen des Vereins für Beförderung des Gewerbflusses*, 1893, pp. 280, &c. So far none of our technical journals here have given full translations of these important contributions.

However, whatever may be the value of considerations as to the influence of carbon, let us refer a little further to allotropic forms of iron. Professor Roberts-Austen, in his reply to the discussion which occurred on the presentation of his report to the Alloys Research Committee in April 1893, stated that the author (that is, of this present paper) failed to distinguish between the hardness or softness of the atoms and the hardness or softness of the mass. At any rate, this view of the subject has also puzzled others, for Dr. F. C. G. Müller, in his paper "On the Critical Points of Steel,"* says when speaking of β iron, "We are faced with the following exceedingly difficult proposition: β iron is as soft as glass and brittle, α iron soft and tough. And this being so carbon is no directly hardening constituent."

Again he states: "According to Osmond, the hardness of steel or white pig iron is not at all due to carbon, but to a hard modification of the iron itself. The iron is said to occur in two different states, namely, 'hard iron' and 'soft iron.' 'Hard iron' exists independently at temperatures above the critical point only; on passing this point a rearrangement of particles takes place, resulting

* *Stahl und Eisen*, vol. xi. 1891, p. 634.

in 'soft iron.' Carbon exerts an indirect influence only in preventing the transformation from the first into the second stage. In due sequence the natural hardness of tungsten steel is attributed to α iron. Even the hardness produced by forging and cold-rolling has been ascribed by Osmond, in his earlier publications, to the transformation of β iron into α iron. To an unbiassed mind, this must sound just as strange as if some one were to assert that the hardness of brass is not due to an alloy of copper and tin but to a β copper, or that in sugar-water the water (*per se*) had turned sweet."

Exactly so. This is the point for which the author contends. Dr. Müller's scientific standing is so well known from the important contributions he has made on metallurgical matters, that these remarks deserve special attention.

Conclusions and difficulties like these must present themselves to those studying the question; and unless those formulating the hypothesis referred to more fully and definitely substantiate their claims, difficulties they must remain, and as serious obstacles to their adoption. . It would seem that advance must now come from the fuller study of micro-structure and analytical methods.

It may be well to also refer to the discussion which followed the reading of Dr. Ball's paper "On the Changes produced in Iron by Thermal Treatment" to this Institute in 1891. Professor Roberts-Austen said, when speaking of certain changes pointed out by Dr. Ball as occurring at high temperatures (about 1300° C.) that if that gentleman's observations were pursued to their logical conclusion, he thought they would have to admit another allotropic change at 1400° C. Mr. F. Osmond had also previously stated in the *Journal of the Iron and Steel Institute* for 1891, No. I. p. 104, with reference to Dr. Ball's observations, "Should a third cause be added to these two, and a *new* allotropic change of iron at 1300° C. be admitted?"

More recently Mr. Osmond stated, he believes that in addition to the α and β forms, there is another condition which he terms the " γ ," formed at lower temperatures. If all these changes or modifications were admitted, surely then iron would be indeed a polymorphous element. Without more definite evidence the author cannot bring himself to agree with such conclusions.

It is naturally to be expected that supporters of opposing theories, each contending in friendly rivalry for the truth concerning a subject admitted by all to be a very complex one, must draw very different conclusions from the same set of experiments. As one opposed to β iron, the author would, however, like to extract a very strong beam of light, so it seems to him, from one on the other side.

No clearer or better statement has been used on this matter when it is said by Mr. Osmond : * “Carbon at high temperatures is very different from the carbon in polymeric compounds with which we are accustomed to deal at ordinary temperatures. It possesses a *particular chemical activity*.” Not in the author’s opinion an activity which produces β iron, but one that forms carbides of most interesting character, and whose properties we yet imperfectly understand, our analytical methods not having yet enabled us to separate them satisfactorily. It would seem that all the facts in this paper also point clearly in this direction.

Although, from the behaviour noticed in regard to certain manganese steel castings at the Hecla Works several years ago, it appeared that the magnetic qualities varied, at the time this was thought to be due to irregularity of material. Probably from the facts here described, this was not wholly the case. Also, when drawing down manganese steel, practically non-magnetic in its original state, to fine wire, similar variation was noticed. This was attributed to the many heatings required to effect this reduction. As will be seen, the particular kinds of heat treatment has, no doubt, much to do with the metal’s magnetic qualities.

The circumstances, however, which first drew special attention to the fact that non-magnetic manganese steel of the usual chemical composition might vary very considerably in its magnetic properties, were the following :—

It was thought desirable to ascertain whether this material could be cemented in the same manner as carbon steel samples. After this treatment they were observed to be exceedingly magnetic, that is, as compared with their original condition. The

* *Journal of the Iron and Steel Institute*, 1890, No. I. p. 45.

experiment was again repeated with the same result. At first the change was thought to be partly due to an increase of carbon resulting from the cementation treatment, but, as will be clearly seen from other experiments hereafter described, this is not so. The curious behaviour noticed is found to be almost entirely due to the particular kind of heat treatment employed. Whether there are changes in the form of the carbon or carbides present, remain to be proved. Probably this is so, and it would appear that it is in this latter direction that we must now look for the true explanation of the peculiar facts noticed.

So considerable is the change in properties that a bar of this non-magnetic material, cemented in the ordinary manner, was afterwards magnetised, and retained sufficient coercive force to lift a small piece of wrought iron, weighing 60 grammes. After being kept several months, this coercive power was lost, showing it to have been only feeble. In order to see the effect of forging and water-quenching, the same sample, now magnetic, was re-heated, forged, and water-quenched in the usual manner. To the author's surprise the sample then became equally as non-magnetic as in its original state.

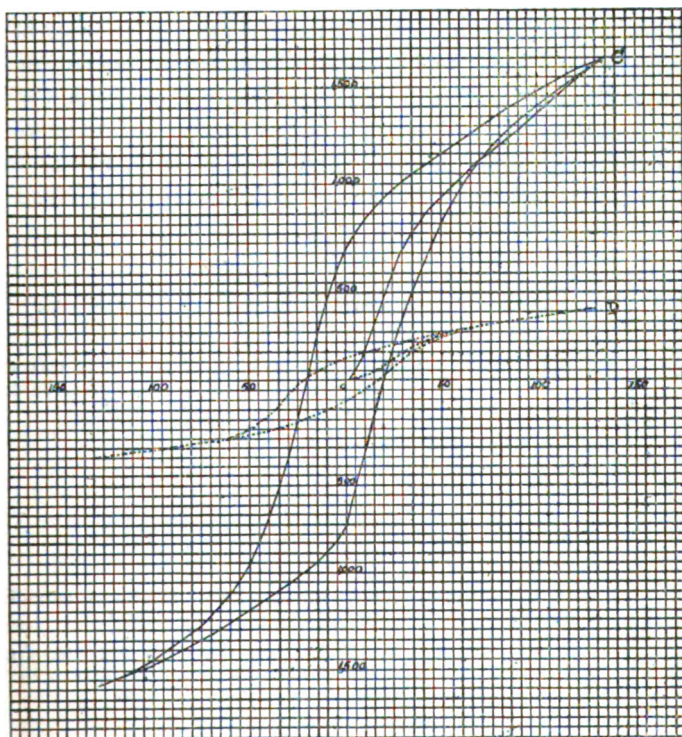
In order to further test this fact, a bar of manganese steel 15 inches long, $\frac{3}{4}$ inch wide, and $\frac{1}{2}$ inch in thickness, of usual non-magnetic quality, was cemented. It became magnetic. Half the bar was heated, forged, and water-quenched, the other half left in the state as received from the cementation furnace; the former, that is, the forged and water-quenched portion, was non-magnetic, whilst the other, or cemented portion of the same bar, was considerably susceptible to magnetic influence: thus a curious combination of magnetic and non-magnetic qualities was obtained *on the same bar*. The author would only add that the sample exhibited to the Institute is one of many bars so treated. This can be tested, in fact any member interested in this line of research communicating with the author, will be willingly supplied with a sample possessing corresponding qualities.

Naturally enough, it might be thought to cementation was owing the entire change of properties noticed; but from the behaviour of other specimens not cemented, but merely heated for a long, continuous period, and which also lost their non-magnetic qualities,

the author feels sure that the change is rather a question of continuous heating (probably changing or decomposing the particular form of carbon or carbide) than an increase or decrease of carbon such as produced by cementation or annealing. To test this a sample was placed in an ordinary annealing furnace for ninety

HYSTERESIS CURVES.

Fig. 1.



hours, probably remaining at a temperature of about 950° C. for one-third of that time. This was also found to have become considerably susceptible to magnetic influence. If the annealing and heating had been continued as long as in the case of the cemented specimens, no doubt the same results would have been obtained, and without any alteration in the amount of carbon present, that is, either as regards increase or decrease. It may be here said that such an annealing as referred to was in no way expected to

reduce the carbon. The heat treatment must be continuous for a considerable time, and probably also must be accompanied by a very slow cooling, such as would naturally occur either in the case in question or in the cementation process. This is specially mentioned, because merely heating manganese steel once or more for a short time, even to very high temperatures, close upon the welding point, will *not*, so far as can be detected, change its non-magnetic character. If the latter were so the curious facts now described would have been noticed at a much earlier stage of the investigations on this steel that have been carried out during the past ten years. Dr. Hicks, F.R.S., Principal of Firth College, Sheffield, has been good enough to make for the author hysteresis curves of the cemented sample. These are given in Fig. 1. Bars were prepared for him, as shown in the following table, No. I. :—

TABLE I.

Mark on Bar.	Treatment.	Magnetic Qualities.	Remarks.
A.	As rolled.	Not attracted by the most powerful magnet.	In a field of 320 C.G.S. the permeability = 1·061.
B.	Similar to A, but water-quenched at about 1100° C.	Same as A.	
C.	Cemented. No subsequent heat treatment.	Considerably magnetic.	See full curve C in Fig. I.
D.	Same as C, but water-quenched.	Much less magnetic than C.	See dotted curve D in Fig. I.
F.	Cemented, forged, and then water-quenched.	Practically non-magnetic and like sample A.	In a field of 325 C.G.S. the permeability = 1·08.

Note.—Sample "A" was a specimen of ordinary non-magnetic manganese steel (1·05 per cent. C, 13·42 per cent. Mn), and from it were prepared with the subsequent treatment named samples, B, C, D, and F.

The above tests were made by Dr. Hicks, F.R.S., of Firth College, Sheffield.

Having treated samples (1) by heating or cementing in order to obtain an increase of carbon, (2) mere continuous heating in which the carbon was not altered, it was then thought it would be interesting to see what would be (3) the effect of decarbonising manganese steel. It was naturally expected that this would be a troublesome operation, as manufacturers of malleable iron castings specially

avoid in their raw material one containing much manganese, as decarbonising or softening—for in many cases the term “decarbonising” is a misnomer—is hindered, if not prevented.

With reference to this latter remark respecting decarbonisation, the author hopes to present a paper to this Institute in proof of the fact that in the preparation of malleable cast iron the entire removal of carbon, or even a removal of the greater portion, as often ordinarily stated, does not occur, or at any rate that some of the most excellent or best qualities of malleable cast iron castings contain as much carbon after a fortnight's so-called “decarbonising” as when originally placed in the annealing ovens. What does happen is, that the carbon changes from that ordinarily known as combined, but now more properly termed hardening carbon, into the graphitic, or, as Professor Ledebur terms it, temper-carbon. This, no doubt, is the reason why manganese is objectionable, as it prevents this ready transference, specially in the material containing large percentages of carbon, as is the case in the material used for the preparation of malleable cast iron. In other words, it would seem that carbide of manganese under these conditions is not readily decomposed or dissociated.

The annealing of this manganese steel was certainly more difficult of accomplishment, but by treating a thin bar, $3\frac{1}{4}$ inches wide by $\frac{3}{32}$ inch in thickness, the object was attained, the carbon being reduced to as low as .06 per cent., or, in other words, a removal of 94 per cent. of the amount originally present was effected. The sample being thin was naturally much scaled. The latter was removed, and the bar was found to possess very considerable magnetic qualities or susceptibility. The same experiments were then carried out as with the cemented samples. A strip now magnetic was heated to various temperatures, then forged and water-quenched, but in *no case* did it again become non-magnetic, as with the cemented or annealed samples. It was now *persistently magnetic*, though according to the analysis apparently no change in the chemical composition had occurred *except as regards carbon*.

Therefore, whilst as regards the cemented samples the change was to some extent independent of the increase in the amount of carbon, in the present case, carbon being absent or nearly so, there was no return of magnetic qualities. It is important to bear this in mind, as here apparently we have a very distinct suggestion

presented, that the magnetic or non-magnetic qualities of manganese steel are considerably influenced by the behaviour of the carbon itself, or by carbide of manganese. If this is found to be so, one's respect for the powers of carbon is still further increased, and it will probably be found to be a proof of another important part played by this element. The more steel and its alloys are studied, the more we seem to be driven back to the conclusion that this metalloid plays *the important part*, and that other elements are to some extent of secondary importance—that is, relatively. Unique is a word that truly expresses the part played by carbon.

The specific gravities of the annealed strips were taken in the various conditions, and will be found in Table II.

TABLE II.—*Showing Specific Gravities of Manganese Steel, also Analysis before and after Decarbonisation.*

No.	Description.	Analysis.			Analysed by	Specific Gravity.	
		C.	Mn.	Fe.		Osmond.	Hadfield.
		Per Cent.	Per Cent.	Per Cent.		Per Cent.	Per Cent.
1.	{ Original sample, non-magnetic }	1·08	12·52	...	Hadfield.	7·81	7·806
2.	{ After decarbonisation }	...	12·45	86·27	Osmond.	...	...
	{ Very magnetic }	0·06	12·45	86·50	Hadfield.	...	7·527
3.	{ Decarbonised and re-rolled from No. 16 to No. 19 B.W.G. Considerably magnetic }	...	...	...	...	7·30*	7·577
4.	{ As No. 3, but water-quenched at about 1100° C. Still considerably magnetic }	...	...	...	...	7·57	7·662

Note.—The behaviour of samples Nos. 2, 3, and 4, which are all considerably magnetic as compared with the same material, non-magnetic in its original state. Sample No. 1 shows that the decarbonisation by reducing the carbon from 1·08 per cent. to ·06 per cent., and this without affecting the manganese, entirely changes the properties of the material, even when in the reheated or reheated and water-quenched conditions. This is *unlike* the cemented manganese steel, which became magnetic, but was again made non-magnetic by water-quenching from about 900° C.

Mr. Osmond, to whom the author has submitted samples of this decarbonised manganese steel, thought at first that possibly the magnetic conditions noticed might be owing to oxidation of some of the manganese present, but both his and the author's analysis clearly show that this is not so. The specific gravities noticed

* Afterwards found to be too low.

are interesting, owing to the variations produced by the different treatment, and it will be important to follow up this point further. Mr. Stead is kindly investigating the conditions in which the carbon is present both in the last-named and also in the cemented samples.

As regards oxidation * being the cause of the magnetic qualities noticed, this of course cannot in any case apply as regards the cemented samples or those annealed in the ordinary way, nor in face of the analyses quoted, is it probable that it applies to the decarbonised sample last described. The conviction therefore is more and more forced upon the author that the curious non-magnetic conditions of manganese steel are in some way due to a particular form of carbide of manganese.† Probably this is a form not yet sufficiently examined or thoroughly known, and one which is varied by cementation or continuous heating, or which can be removed in thin samples. Thus, we have a non-magnetic material, such as manganese steel, able to change its character by the following treatments :—

* Mr. L. T. O'Shea, B.Sc., of Firth College, Sheffield, made an interesting report in a paper given to the British Association in 1890, on "The Effect of Oxidation on the Magnetic Properties of Manganese Steel, in the form of Drillings."

† Since writing this paper the author has found a remarkable confirmation of his opinion respecting the strong influence of carbon upon magnetic properties, in a communication by Dr. Hopkinson ("Magnetisation of Iron," *Royal Society Proceedings*, 1885, Part II. p. 462), which gives the following interesting facts :—

Dr. Hopkinson's Mark of Specimen.	Material examined.	Condition.	Carbon.	Manganese.	Permeability.	Susceptibility.
			Per Cent.	Per Cent.		
X.	Hadfield's manganese steel	Forged	1·00	12·36	1·27	0·0215
XIV.	"Low" manganese steel	Forged	1·29	8·74	3·59	0·206
XVI.	"Low" manganese steel	{ Forged and oil hardened }	1·29	8·74	3·57	0·2046
XXXV.	Spiegeleisen	As cast	4·51	7·97	1·84	0·0668

This clearly shows the remarkable influence of carbon.

Samples Nos. 2, 3, and 4 were practically of the same manganese percentage, but the spiegeleisen, No. 4, contained 4·51 per cent. carbon, against 1·29 per cent. in the "low" forged manganese steel, Nos. 2 and 3. Both the permeability and susceptibility of the latter were almost twice and three times, respectively, that of the former (spiegel). Carbon, or the particular carbide present, is evidently the cause of this difference, as the manganese is practically the same in both cases. To the author this seems to be a most remarkable proof.

1. Cementation.

2. Continuous heating for a considerable period, either at low or high temperatures, but without changing the amount of carbon or manganese present.

3. Decarbonisation by methods such as used for the production of malleable cast iron.

Other materials, too, besides manganese steel, seem also to distinctly point in the same direction as above referred to. Let us take the case of a special sample of malleable cast iron, one that was referred to by the author during the discussion on Professor Ledebur's recent paper before this Institute "On the Modifications of Carbon in Iron." This sample after annealing contained 3.07 per cent. of graphite or graphitic temper-carbon, as named by Professor Ledebur. It was soft, and could even be forged at fairly high temperature; but as soon as water-quenched, whether in the original cast or subsequently forged state, it became exceedingly hard, and then possessed glass-scratching hardness.*

Professor Ledebur, to whom the author has sent samples of this cast malleable iron material, has been good enough to say he considers the experiments described as follows will throw a new light on the relations existing between iron and carbon. It would, therefore, seem worth while to follow up this aspect of the case still further.

Now, even with our present comparatively imperfect analytical methods, that is, as regards accurately detecting and separating the various forms of carbides, in this case we know that the change of hardness is due entirely to a change of form in the carbon or carbides present. The analyses in Table III. enable these changes to be readily traced. In an ordinary steel analysis this is not so apparent, as unfortunately we now speak of the carbon present in, say a carbon tool steel, whether in the normal or quenched state, as being of the same character. In both the carbon is

* Mr. Moissan, in an interesting paper to the *Société des Amis des Sciences*, Paris, May 17, 1893, has made a number of interesting researches on carbon and its different forms, and found in diamond-bearing sand from the Cape district distinct evidence of the presence of graphite. Moreover, he has in the electric arc reduced the diamond to graphite.

described as "combined," whereas, as so clearly shown by Professor Ledebur, this is not so.

TABLE III.—*Professor A. Ledebur's Method of showing Analyses of Forged and Cast Steel in the Annealed, Hardened, and Tempered conditions.*

CAST STEEL NOT FORGED.				
Description.	Specimen A.		Specimen B.	
	Before Annealing.	After Annealing.	Before Annealing.	After Annealing.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Hardening carbon	0·14	0·08	0·36	0·16
Carbide carbon	0·44	0·52	0·62	0·92
Graphite and temper-carbon . . . .	...	0·01	...	0·01
Total carbon	0·58	0·61	0·98	1·09
Silicon	0·23	...	0·28	...
Manganese	0·18	...	0·20	...
TOOL STEEL.				
Description.	As Forged.	Hardened.	Hardened and Tempered at Blue Heat.	
	Per Cent.	Per Cent.	Per Cent.	
Hardening carbon	0·22	0·65	0·36	
Carbide carbon	0·71	0·38	0·67	
Graphite and temper-carbon . . . .	...	...	...
Total carbon	0·93	1·03	1·03	
Silicon	0·11	...	...
Manganese	0·11	...	...

Note.—These analyses throw much light on the changes in the form of carbon, which occur by thermal treatment of steel. They show how much there is wanting in our present methods of analysis. With the increasingly severe tests stipulated by the mechanical engineer, more attention will have to be paid to the different states or forms assumed by the carbon present in steel.

The subject is so complex that it is not possible to separately deal with it in this paper, but enough has been said to indicate that in this important branch of metallurgical research there is much which the practical steel maker will soon find it necessary to touch and handle.

Those interested are referred to Professor Ledebur's various interesting papers on this question.

A list is given in the bibliography accompanying this paper.

With reference to the various forms of carbon shown in the table, the author gives the results of these experiments by Professor Ledebur on carbon cast steel, annealed, hardened, also hardened and tempered, as they may be of interest. The forms of carbon are there clearly separated in so far as research work has enabled the accomplishment of this.

In the specimens of malleable cast iron above referred to the great changes which have occurred are, however, brought out even by the ordinary imperfect methods of analysis. Table IV. very clearly shows the differences.

TABLE IV.—*Changes Produced in Cast Malleable Iron by Heat Treatment and Water-Quenching.*

No. of Specimen.	Whether Subsequently Forged.	Tested in Cast or Subsequently Forged Condition.	Nature of Treatment.	Temper at which Water-Quenched.	Specific Gravity.	Combined Carbon by Ordinary Colour Test (Eggertz).	Graphite or Graphitic Temper Carbon.†	Percentage of the Two Forms of Carbon added together.	Total Carbon by Combustion.‡	Total Carbon in Original Sample.	Carbon Unaccounted for by Ordinary Analysis.	Remarks.
1	No	Cast	None. Tested in original condition	...	7.28	trace	2.07	= 3.07	3.07	3.07	...	This represents the sample in original state.
2	No	Cast	Hardened	920°C.	7.16*	0.83	1.74	= 2.57	2.55	3.07	0.52	
3	Yes	Forged	Heated to 920°C and cooled in air	...	7.23	0.53	2.24	= 2.77	2.73	3.07	0.34	
4	Yes	Forged	Hardened	920°C.	7.38	0.70	1.64	= 2.34	2.23	3.07	0.84	
				C.	Gr.	Si.	S.	P.	Mn.			
Analysis of original sample				trace	3.07 §	0.23	0.04	0.20	0.26 per cent.			

Therefore, whilst we had 3.07 per cent. graphite in the original cast sample, and only a trace of what is usually termed combined

* This being so low it was repeated; the second determination showed 7.15 specific gravity.

† Iron dissolved in nitro-hydrochloric acid. Silica separated by soda, washed and graphite burnt off.

‡ By cupro-ammonium-chloride method.

§ The specific gravity of the graphite or temper-carbon separate was 2.25. It was entirely non-magnetic, showing that it had been thoroughly separated from any iron originally present.

carbon, after quenching No. 2 specimen the graphite was only 1·74 per cent., and the combined carbon had become 0·83 per cent. The remainder, ·62 per cent., was unaccounted for, and must be present in some other form not easily detected by ordinary analytical methods. We know that no carbon could be lost by merely heating, because even a fortnight's previous annealing had still left the total carbon present as high as 3·07 per cent. As before stated, these results again also contradict the ordinarily accepted notion that malleable cast iron is obtained by completely decarbonising an ordinary white cast iron.

A paper communicated to another Society (not in this country), some years ago, described the process of producing malleable iron castings, but was unaccompanied by a single analysis. The author, nevertheless, seemed entirely satisfied with the ordinarily accepted explanation that the process was one which removed practically all the carbon—in other words, that the samples were decarbonised. Whilst in some specimens of English malleable cast iron a considerable portion is removed, yet in the excellent American samples referred to, and in which, after annealing, 3 per cent. of carbon remained in the form of graphite or graphitic temper carbon (probably as much as was originally present before annealing), we see that removal of carbon is not necessary to obtain the desired product, viz., a soft and tough casting. All that is required is the transference from the hardening to temper or graphitic temper-carbon.

It may be interesting to state that a turning tool was forged from a piece of this malleable cast iron, hardened and used in the lathe, with as satisfactory results as might be expected from a sample roughly prepared. The nose of the tool could not be touched with a file after it was hardened, and two cuts (a "skin cut" and an "under-cut") 7 inches long were taken off an ordinary rolled Bessemer steel bar before the edge of the tool gave way. Although the material was exceedingly soft in the cast state, and did not contain even a trace of combined carbon, the fact of its hardening so as to give a turning tool a good cutting edge shows that the often accepted theory as to the method adopted in producing malleable cast iron effecting an entire decarbonisation is incorrect.

A material of similar quality to that of the American samples is described in the *Proceedings of the Sheffield Metallurgical Society* for May 1891, in an interesting paper by Mr. B. W. Winder respecting black file steel. This product results from the careless treatment or overheating of hard carbon steel (1.50 per cent. C.) used in the manufacture of files. After such careless treatment this material is sometimes found to contain so much as 0.76 per cent. graphite or graphitic temper-carbon. In this case, curiously enough, and unlike the author's tests on the cast malleable iron samples, it was found by Mr. Winder that the graphite remained practically the same after water-quenching. Although no actual analyses are given by him, he stated that neither re-heating, hammering, annealing, nor hardening changed the graphitic carbon present.

Under the circumstances, and seeing the facts now described both as regards the malleable iron and manganese steel samples, in the former case this material is certainly a semi-steel, does it not seem unnecessary, in order to explain the hardness produced in steel by water-quenching, to call into play a hypothetical explanation that iron is changed from the α , or soft state, which all admit, into the supposititious or β hard form. The alterations in the carbon or carbide seem themselves quite sufficient to account for the remarkable changes in the properties of the material. During the discussion on Dr. Ball's paper, previously referred to, it was admitted by those supporting the theory that there was just cause for disappointment that β iron had not been isolated. This was stated three years ago, and it will be acknowledged that even from the latest research work that we are no nearer such a desideratum.

As those engaged in this interesting research work may wish to refer to the special literature on the question here considered, the writer has prepared a bibliography to accompany this paper in the hope that it may prove of service.

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- Professor A. LEDEBUR.—“*On the Modifications of Carbon in Iron.*” (Journal of the Iron and Steel Institute, No. II. 1893.)

DISCUSSION

ON PROFESSOR ARNOLD'S AND MR. HADFIELD'S PAPERS.

Professor W. C. ROBERTS-AUSTEN, Member of Council, remarked, that there were so few who applied the results of physical research to the industrial problems connected with iron and steel, that it was natural to look with great interest to any work which came from Sheffield, whence so much had already been received. Apart from her early technical pre-eminence in the manufacture of certain varieties of steel, the knowledge of the constitution of steel in modern times seemed to centre in Sheffield. In 1861, Vickers was one of the earliest to insist on the necessity for correlating the chemical constitution and the mechanical properties of steel. Sorby pointed to the vital importance of studying by the aid of microscopy the structure of carburised iron, and Hadfield, by describing a varied series of alloys of iron, had conferred a precious gift on metallurgy, for which it would be difficult to thank him adequately.

But to turn to the laborious work now offered by the author of this paper, it would be well to try and point out wherein the interest of such work consisted, and to show what measure of success the author had attained. At the outset, it was impossible to forget that many members of the Iron and Steel Institute were not familiar with the fact that certain well-known elements could assume states in which they behave abnormally, and the same element might therefore appear to be, even if analysis proved it to be pure, two or even more absolutely distinct bodies. If, for instance, melted sulphur were cooled down from a temperature of 300° , the temperature would fall continuously until 210° was reached; there would then be an evolution of heat, and the mass would continue to cool until a temperature of 110° was reached, when there would be another evolution of heat. At this point, prismatic crystals would form, but these prismatic crystals might change spontaneously into octahedral crystals, and these latter were soluble in bisulphide of carbon, while the prismatic crystals were not. A clear case was thus presented

of the connection between the change in crystalline structure and allotropy. Further than this, if the sulphur were quenched at a temperature of over 210° , it remained plastic and stretched like india-rubber, and was, moreover, only partly soluble in bisulphide of carbon; but what was, perhaps, still more curious, if this plastic sulphur, at a certain stage, were stretched beyond its limit of elasticity, it passed into the crystalline variety, which was, of course, very hard in comparison with the plastic form it so recently possessed. The question of the allotropy of bodies was one of the most interesting in the whole range of natural phenomena. Allotropy was common in non-metals, and as it proved to be of great industrial importance, should not every effort be made to trace its existence in those bodies which are called metals? This many observers, including Faraday and Joule, had attempted to do. Mr. Osmond had been in the front rank of such workers; nevertheless, the history of the subject, as written by the author of the paper, suggested that the allotropy of iron had been invented by Mr. Osmond and adopted by Professor Austen. Turning to the behaviour of iron, close analogies to that of sulphur were found. If carburised iron, say, very mild steel, were cooled down from a temperature of 1000° C., the temperature fell continuously and uniformly until 860° was reached; then there was an evolution of heat, and the normal rate of fall in temperature was resumed. At 740° , however, there was a second evolution of heat, followed, as before, by a resumption of the normal rate of cooling; but at 650° there was a third evolution of heat, and again the normal rate of cooling was resumed. Moreover, just as one kind of sulphur was soluble in bisulphide of carbon, and another kind was not, allotropists urged that a certain kind of iron, such as that which existed at a temperature of over 650° C., possessed special properties in relation to carbon. Furthermore, as in the case of plastic sulphur, which became hard on stretching, so cold, solid, but *plastic iron* on stretching also became hard—a fact to which reference would be made subsequently.

Evolution of heat on cooling, or absorption of heat on heating, taken in conjunction with altered physical properties which were met with in the thermal treatment of steel, were undoubted evi-

dences of allotropy, and allotropists urged that this evidence was of great service in enabling its remarkable properties to be explained. In the case of iron, however, the action of carbon could not be ignored. Both Mr. Osmond and he had always insisted on the importance of the part played by carbon. In his lecture at the Newcastle meeting of the British Association, which was the true origin of the present discussion, he (Professor Austen) stated that the presence of carbon was essential to the hardening of steel; and Mr. Osmond had again and again emphatically insisted on the importance of the action of carbon; but both considered that its action alone did not explain all the known facts of the hardening of steel, and the reasons which led to the belief in the allotropy of iron were well summed up by Mr. Osmond in his contribution to this discussion. Among these reasons was the occurrence of a change at 855° in electro-iron, which had so high a degree of purity that there appeared to be nothing in it but 0.007 per cent. of carbon and 0.005 per cent. of sulphur.* Mr. Osmond finds even less—0.002 per cent.—in the electro-iron he used. The author of the paper originally attributed the occurrence of this important point, called by Mr. Osmond Ar3, to the presence of hydrogen. Now (1894) the author of the paper attributed it "to the combined action of sulphur and a sub-carbide of iron," and his argument was based on the fact that he obtained some very impure electro-iron, containing 0.15 per cent. of sulphur and 0.018 per cent. of carbon, and found that when this, for electro-iron, strangely impure material was heated, the point Ar3 was found to be well developed in it. He (Professor Austen) suggested that if the author of the paper would calculate what evolution of heat could be attributed to the formation of sulphide of iron from the 0.15 per cent. of sulphur present in his electro-iron, he would find that it was somewhere about one-twentieth of the amount of heat that was actually evolved when electro-iron was cooled to 860° (Ar3). But in order to dispose of the question of the action of the minute quantity of sulphur which he (Professor Austen) had always admitted was present in certain kinds of electro-iron, he had deposited iron from

* The fact that electro-iron prepared from the double sulphate of iron and magnesia contains this amount of sulphur was communicated to this Institute by Professor Austen so long ago as 1887 (*Journal*, 1887, No. I. p. 71).

the chloride of iron and ammonium; and in this iron, in which only a minute percentage of sulphur beyond the second decimal place could be detected by analysing 13 grammes, the point AR_3 was found to be well developed, not in a single experiment, but in curve after curve, representing the autographically recorded results of the repeated heating and cooling of the iron. This, he trusted, would show the author of the paper that the cause of his fear as to the disturbing action of sulphur in the case of the original experiments on electro-iron had been removed, and with it much of the author's case also disappeared.

Now, another point on which the author of the paper laid much stress was the observation of Mr. Osmond that the presence of boron in iron lowered the position of AR_3 , and he considered the evidence as to the existence of combined boron in the specimen of iron used by Mr. Osmond as being of the "most trivial nature." The author of the paper seemed to be entirely ignorant of the evidence given by Mr. Osmond* in favour of the existence of combined boron in this specimen. If boron was not in intimate union with the iron, why was the point AR_3 lowered? On the question of boron steel further evidence would be offered in the course of this discussion. The author of the paper had failed to effect the union of boron and iron, but there was no difficulty in obtaining alloys of boron and iron containing 10 to 23 per cent. of boron. Troost and Hautefeuille prepared such alloys in 1876, and, what was more, had worked out the heat of combination of boron and iron.

The author of the paper now considered that the evolution of heat at the point AR_2 marks "a physical point due to the passage of hot iron from the plastic to the crystalline state." It was evident, therefore, that his reluctance to admit the existence of an allotropic change in iron must in no small measure be due to a misconception as to the meaning of the term "allotropy." The evolution of heat accompanying a change of iron from a plastic to a crystalline condition, and the altered properties of the mass, was as good evidence of allotropy as could well be afforded. It was not, however, the first time that doubt had arisen as to the suitability of the nomenclature employed in connection with the chemistry

* *Transformations du Fer et du Carbone*, p. 11.

of iron, and he might refer to an author who was formerly much quoted in illustration of the point; for his hearers who had read "Pickwick" would remember, in this connection, the observations of the younger Mr. Weller. Sam thought that *chalybeate* was "a werry inexpressive word for describing the uncommon strong flavour o' warm flat-iron" possessed by the ferruginous waters of Bath. The author of the paper probably thought that allotropy was a "very inexpressive word," but it was nevertheless one which was generally accepted for describing the phenomena he had observed.

Turning to the present state of our knowledge of the constitution of iron, and our view as to the existence of a hard β modification, no doubt much theory had always been involved, and the difficulties naturally increased as the consideration of the question was approached. As regarded the separation of the points AR3 and AR2, absolutely nothing was due to the author of the paper, because the recognition of the fact that the points are separate originated with Mr. Osmond himself, and his views on the subject were stated in a letter to him (Professor Austen), written in March 1891, and publicly in a report dated 28th January 1892. The clear separation of the two points AR3 and AR2 by Mr. Osmond pointed to the possibility of modifying the views originally expressed. The recognition of the separation mainly depended on the magnetic behaviour of iron; but the author of the paper stated, "It is now generally admitted that the appearance and disappearance of magnetism coincides with the point AR2, which occurs at about 100° C. below AR3." It was no longer admitted that the magnetic change coincided with the point AR2, and the author's statement was very inaccurate, and showed how little he could be conscious of the difficulty of determining the point at which magnetism really appears in red-hot iron. This question has occupied Mr. Tomlinson and himself in such time as they could work together during two years, and they were absolutely satisfied that in the case of electro-iron in which no carbon could be detected by the most careful analysis,* and in which sulphur was not present in

* It is difficult to understand why the electro-iron used by the author should be so impure (0.15 per cent. sulphur and 0.18 per cent. carbon). Professor Austen, who has

quantities exceeding a small percentage in the *third decimal place*, that magnetism even in a weak magnetic field reappears not at 740°, but at 802°, midway between AR2 and AR3—that was, before the vital change from the plastic to the crystalline state had made progress. Professor Tomlinson would, however, deal with this point, but until the separation of the points AR3 and AR2 was absolutely established, it would be premature to say anything very definite as to the modification of the originally expressed views.

The great metallurgist, Bergman, in 1781 called iron “polymorphous,” and it might be necessary to recognise the existence of three varieties of iron (just as there were three varieties of sulphur); but nothing had been urged by the author of the paper which showed that quenched steel did not owe its hardness to the existence of an allotropic β variety of iron. He (Professor Austen) saw no objection whatever to the simultaneous existence of both α and β iron in hard magnetic steel, which had evidently been a difficulty to Mr. Hadfield.

It would be impossible, within the narrow limits of the discussion, to re-state the arguments which led physicists to recognise the fact that the molecules of an element may be hard and the mass soft. As regarded the existence of a hard variety of iron, it should be remembered that a great consensus of work showed, that in the series of simple elements the hardness increased with the number of atoms, and was it not reasonable to conclude that when the molecules become simplified by heat, and their numbers consequently augmented, that their hardness augmented also? The views he and Mr. Osmond had promulgated had at least led to one result of great interest and importance, as it had led Mr. Werth to foretell the synthetical production of the diamond, and the celebrated chemist, Mr. Moissan, to realise it. Mr. Werth urged that the hardest form of carbon, the diamond, was the normal form of carbon at a very high temperature, and that, in

had great experience in the deposition of electro-iron, found no difficulty in obtaining from the double sulphate of iron and magnesium iron containing only 0.005 per cent. of sulphur, and 0.007 per cent. of carbon. These elements probably come from the sulphate on the one hand, and the carbonate of magnesium used to neutralise the bath. In the preparation of the sample above described, *chloride* of iron and ammonium was used, and the presence of both sulphur and carbon has thus been avoided.

order to maintain it in this form, it was necessary to cool highly heated carbons *rapidly under pressure in the presence of an element of small atomic volume*.^{*} And these were precisely the conditions which enabled Mr. Moissan to produce the diamonds which would be exhibited that very evening to the Royal Society.

As regarded the influence of the atomic volume of elements added to iron, he must refer readers to his Second Report (1893) to the Research Committee of the Institution of Mechanical Engineers. His friend, Mr. Osmond, in his communication to this discussion, had fully dealt with the matter, and had incidentally shown that Mr. Osmond and he claimed their friend Mr. Hadfield as an ardent, and indeed advanced, disciple in respect to the influence of the atomic volume. Mr. Hadfield, however, had great difficulty, as his very interesting and important paper shows, in realising that mechanical stress could effect the passage of soft iron into hard, and notwithstanding the elaborate bibliography which accompanies his paper, he appeared to have overlooked memoirs of real importance which bear upon the subject. He (Professor Austen) therefore directed attention to the work of Professor C. Barus, one of the most distinguished and patient physicists of the great nation which has produced Willard Gibbs, and Rowland. Professor Barus had said,[†] with reference to the work of Osmond, that "the possibility of molecular change in a metal corresponding to each change of strain imparted to it, is steadily gaining in probability;" and further, Professor Barus points to the experiments on the viscosity of strained steel, which led Carus Wilson to summarise his experience as to the conversion of α into β iron by stress "in favour of Osmond's view." Professor Barus further urged (p. 128) that if all the molecules passed from Osmond's β to his α state together, the iron or steel would necessarily be liquid. "This extreme possibility," he added, "is, however, at variance with the well known principles." He (Professor Austen) had already expressed his belief in the simultaneous presence of α and β iron in hardened steel. Furthermore, as regarded β iron, which Professor H. Le Chatelier had said almost certainly exists in manganese steel, many observers would agree

^{*} *Comptes Rendus de l'Académie des Sciences*, vol. cxvi., 1893, p. 323.

[†] *Bulletin of United States Geological Survey*, 1892, No. 94.

with Mr. Charpy* as to the great importance of the evidence based on the results of molecular change of iron which was effected by stress. Mr. Charpy pointed out, that fact which tended most to confirm the view as to the allotropic transformation of iron was afforded by the peculiarity of the tenacity curve, in which stress (load) and elongation were co-ordinates. That peculiarity consisted in the development of a horizontal line in the curve, and was met with in annealed iron and steel, and in no other metal. He was led to conclude that the abnormal elongation which was produced by a certain stress in iron and steel coincided with the occurrence of an allotropic change in the metal. He confirmed this view, as Carus Wilson also did, by magnetic observations on iron and steel, which showed that when submitted to mechanical tests, there was a certain point at which the physical properties of the metal changed. In a later paper recently published, entitled "The Allotropic Change of Iron," Mr. Charpy not only confirmed, but extended the views he had already expressed.†

It would thus be seen that there was much testimony of the highest order to show that soft iron was converted into hard iron by mechanical stress, and it was well known that this change in hardness was unaccompanied by any change in the carbon, as the experiments of Sir F. Abel and of Mr. Osmond showed.

As regarded the main conclusion at which the author of the paper arrived—"1st. That the ultimate physical influence of elements on iron is not governed by the periodic law," Mr. Osmond had shown, as fully as was possible within the limits of a discussion, that the author of the paper, by adding 1.5 per cent. of certain elements to iron, had sought to verify the "law of Roberts-Austen" under conditions in which it was never claimed that it had force. Briefly stated, the author's second conclusion was that no element except carbon had, *per se*, the power of conferring upon iron the power of abrasion hardness, and that the alleged allotropy of iron was not of practical importance. He (Professor Austen) had, he trusted, offered abundant evidence to show that the question of allotropy in iron was of great importance. Mr. Osmond's own curves rendered it possible to deduce the amount of heat which

* *Comptes Rendus de l'Académie des Sciences*, vol. cxvii., 1893, p. 850.

† *Ibid.*, vol. cxviii., 1894, p. 868.

were due to the allotropic changes (AR3, AR2) and to the carbon change (AR1) respectively. Simple calculations, based on the data afforded by these curves, showed that the point of heat evolved at the point AR1 (650°) was proportional to the amount of carbon present, but the sum of the other quantities of heat evolved (AR3, AR2) was *practically constant in amount, and was independent of the action of the amount of carbon present*. Was it nothing that such an important physical constant should have been carefully studied? And if, as Mr. Osmond contended, there was a purely molecular change in iron, it must be of great importance in the mechanism of hardening steel. Was it nothing to have shown that the presence of an added element has great influence in shifting the points at which the respective changes in iron occur? Although the presence of carbon was essential to the hardening of steel, the changes of the carbon do not enable all the facts to be explained. Was it well for a teacher in the technical school of one of our most important national metallurgical centres, to treat as of no importance the work of a distinguished foreigner, a member of this Institute, who had devoted his life both to industry and to science?

He (Professor Austen), who had so often reminded scientific men of the debt they owed to industrial work as a basis of scientific progress, could at least rejoice with the author of the paper that science has succeeded in gaining admission to the workshop, and was gradually commanding the confidence of the workmen; but, with a full sense of his responsibility, he urged that this was the very reason why the leading practical men should be invited to study working hypotheses.

The author had given, as the conclusion of his work, four statements by way of a general summary of the evidence against the existence of β iron.

1st. The author stated that it was generally admitted that the appearance and disappearance of magnetism coincided with the point AR2, which occurred about 100° C. below AR3.

To this he answered, that the point AR3 was intimately connected with the magnetic changes in iron, and that the point AR2 was, therefore, less important in this respect than the author thought.

As regarded the author's—

2nd conclusion, this related to experiments of Mr. Hadfield, and would be dealt with in discussing his paper.

3rd. The author stated that he found the point $A\epsilon 3$ developed at the highest temperature and greatest intensity in mild steels containing from 0.06 to 0.16 per cent. of carbon. That conclusion was entirely in favour of the views expressed by Mr. Osmond and himself.

4th. The author stated, and attached great importance to the point, that the preparation of a considerable mass of iron free from sulphur was a matter of difficulty. There was, however, no difficulty in obtaining in ample quantity electro-iron which contained less than 0.002 per cent. of sulphur, and that the author should, therefore, have discarded the impure electro-iron which contained 0.15 per cent. of sulphur, or should have classified it with his series of sulphur-iron.

Finally, the author of the paper had claimed one section of it as being "historical," but had hardly alluded to the work which had been done by physicists, and had, moreover, omitted to give what would have been very interesting—the history of his own conversion to the adoption of the methods and appliances which had been so fully and accurately described years ago by Mr. Osmond.

Professor Austen added, that his friend Professor Carl Barus, of Washington, wrote to him as follows, in a letter dated the 23rd of April last:—"With regard to the molecular change of α to β iron . . . it is rather something which, in the solid, corresponds to the change from gas to liquid and from liquid to solid. It seems to me to be a phenomenon of the same order. . . . In brief, therefore, I would say that the solid change α to β involves a molecular change to the same degree in which the change from gas to liquid or from liquid to solid involves a molecular change." This view was also shared by so eminent an authority as Dr. John Hopkinson, and he (Professor Austen) entirely agreed with it, though he was himself inclined to extend it.

With regard to the interesting paper which Mr. Hadfield had just communicated to the Institute, he had very few observations to offer. In the first place, the author of the paper had expressed

his intention of presenting to the Institute a paper in proof of the fact "that in the preparation of malleable cast iron the removal of carbon did not occur." Professor Austen was glad to hear this, because years ago (1881) M. Forquignon had, in the course of an elaborate investigation, come to the conclusion that, as Mr. Hadfield anticipated, there need be no elimination of carbon during the production of malleable cast iron, and as that view entirely differed from the views which were accepted before Forquignon's work was published, it would be specially interesting to have his results confirmed. As regarded the main point in Mr. Hadfield's paper, it was claimed that the singular magnetic change in the bar of manganese steel was probably due to the presence of a carbide of iron, and not to a molecular change (β iron) in the iron itself, which was a very interesting conclusion; but Professor Austen pointed out that there is also strong evidence that molecular change in the iron itself, apart from any altered relation between the carbon and the iron, was followed by resumption of the magnetic property. In proof of this Professor Austen produced a little bar 3 inches long of iron, containing 25 per cent. of nickel and some 1 per cent. of carbon. The bar was originally non-magnetic, but one half had been reduced by plunging it into solid carbonic acid and ether to a temperature -50° C., and by this extreme freezing had, under the influence of terrestrial magnetism only, become magnetic. Half this small bar was therefore a magnet, while the other half was not. This change must be due to a molecular *change in the iron itself*; it could not be due to the formation or liberation of a carbide of iron, unless it was admitted that such a carbide was formed at a temperature of -50° , which would be far more wonderful than the allotropy of iron.

Mr. J. E. STEAD said that the result of Messrs. Osmond's and Roberts-Austen's work in the past had been of great interest, and Professor Arnold had in a great measure confirmed it, although he did not, however, exactly agree with their hypotheses. Although he (Mr. Stead) was inclined to believe in the physical and chemical hypotheses of Professor Arnold, there were still difficulties to remove before they could accept them as finalities; and they

heartily bade those gentlemen to go on with their research work until they were in complete harmony one with each other, which he was sure they would finally be. What they wanted was direct, solid fact; and if, when all the facts that could be obtained were obtained, they did not agree with the pre-conceived theory, the theory must be modified. Professor Arnold was to be congratulated upon his very excellent and admirable work. The amount of work involved in his paper was simply stupendous. Any of those who had done original work at all must know what a terrific amount of burning the candle at both ends was required before such a result could be attained. He had therefore to welcome Professor Arnold as one of their foremost original investigators, and hoped that he would frequently favour the Institute with communications of a similar kind. The particular remarks that he had to make were with reference to Mr. Hadfield's manganese steel, and the cause of the magnetic and non-magnetic peculiarity in it. In the working of the little polishing machines which he had exhibited for the inspection of the members, he experimented with that identical steel. He had used all that he had except the piece he held in his hand, which he intended to keep as one of the greatest prizes he had on earth. It was certainly most wonderful. Professor Martens said that he was tingling with anxiety to get a piece of it, and he was sure that every metallurgical student who had interested himself in the work would be; and as the amount was limited, he suggested that Mr. Hadfield should carefully preserve the balance. In experimenting with the material for preparing microscopic specimens, it was found that a very extraordinary structure developed on etching the surface of the steel. He held in his hand a sample of that extraordinary material, which was magnetic by cementation. It was observed that there were very hard projections after etching which projected well above the surface of the steel. On the prolonged action of dilute acid, dissolving away the soft portion of the steel, the steel block could be used as a printing-block. After dissolving the bar very slowly in Sir Frederick Abel's solution and scraping away the outside portion, it was found that what was removed consisted in great part of a substance in scales very like graphite, though it was not graphite at all; and this material was collected in sufficient

quantity to make an approximate analysis. He had before him a portion of the material, which, it would be seen, was very much like kish; but, as a matter of fact, it was probably a double carbide, or a mixture of carbides of iron and manganese such as Professor Arnold had alluded to. On analysing the material it turned out to contain :—

	Steel. Per Cent.	Carbide. Per Cent.
Iron	85·80	74·0
Manganese	12·18	17·19
Carbon	1·77	6·60
Matter not determined	0·25	2·81
	Magnetic. Non-magnetic.	

Unfortunately in the time at his disposal he could not hit upon an exact method of determining the precise proportions of the



FIG. 2.

carbide in the steel, but by microscopic measurements and by other considerations he had estimated that there was at least from 25 to 30 per cent. of that carbide present. By consulting the micro-photograph (Fig. 2), the proportion of the white lines to the whole mass would be seen; but that did not give the proportion present exactly, however. For it must be remembered that the plates or scales ran in all directions. The lines only represented the edges of the white carbide projecting; the flat plates were not shown,
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but by careful microscopic measurement and other means he estimated that there was 25 or 30 per cent. of carbide present. What did that lead to? It meant that the balance other than carbide contained little or no carbon at all. If there was 25 per cent. present, the 75 per cent. remaining would contain 0.27 per cent. of the carbon. As the carbide was not magnetic, it was clear that the magnetic properties must have been monopolised by the non-carbon iron and manganese remaining. The proof that a carbide separated, leaving a carbonless metal, almost exactly confirmed the microscopic deductions of Dr. Sorby, when he found "ferrite" in the steel, which he said was laminations of pure free iron. The corresponding alloy of pure iron and manganese was undoubtedly in the cemented manganese steel. What did that lead to? Looking at Mr. Hadfield's results, they found that immediately he removed all the carbon from his manganese steel, nothing he could do to the steel would take away its magnetic properties. In looking at the matter, it had struck him (Mr. Stead) that there were three possible explanations of this. First of all, during the prolonged heating there might have been actual separation of manganese and iron, and in the compound those two metals might be actually separated although side by side, and the free iron in that case would exhibit its peculiar magnetic property. Secondly, the manganese might have been actually oxidised in the mass, leaving the iron in a free state—manganese being more readily oxidisable than the iron. That was the other hypothesis. The fact that the material could be rolled negatived this theory. The third was that the manganese did not take away the property of magnetism from iron unless carbon was present. That was the hypothesis that Mr. Hadfield had advanced, and it certainly seemed to him (Mr. Stead) necessary to make only one single test to settle once for all whether that was so or not. He had no doubt that even those who had not followed the question at all would see at once that the proper thing to do was to make an alloy of manganese and iron, to melt them together free from carbon, and find out whether that was magnetic or not. The difficulty was to get pure manganese free from carbon. Mr. Hadfield had sent him some manganese with only $\frac{1}{2}$ per cent. of carbon in it. After having carefully analysed it, a small quantity remained,

quite sufficient for making an experiment. He alloyed this with pure iron by melting them together in a clay crucible. The alloy contained 23 per cent. of manganese, a very much larger quantity than Mr. Hadfield had made in the shape of manganese steel. In order to make it fusible—his arrangements were not sufficiently perfect to get the great heat required to melt a pure alloy—there was just sufficient phosphide of iron introduced to cause the stuff to run down. Phosphide of iron itself was magnetic, but phosphide of manganese was not magnetic. Manganese was not magnetic, so that the presence of phosphorus was not at all detrimental to the result. It would be seen that the steel was clinging fast to the magnet, yet it had 23 per cent. of manganese. The experiment was so far imperfect that he could not actually obtain a material perfectly free from carbon. The compound before them had really got 0.30 per cent. of that element, but it was not large enough to form the carbide in sufficient quantity to obliterate the whole of the magnetism. It was distinctly magnetic, but not as magnetic as it would be if there were no carbon present. If he had known that Mr. Hadfield had intended to read his paper at this meeting, he would have pushed on the work more quickly. The experiment had only been done two days ago, and it meant working all night in order to obtain the final results. He had, however, a quantity of notes for other experiments, the outcome of the work, which he hoped in time to be able to communicate to the Institute. A very important point had been raised by Professor Arnold, namely, on the effect of arsenic in iron. At present they were rather troubled with the idea that arsenic was a very fatal thing in steel. There were certain specifications which stipulated that the amount of impurity should be expressed as phosphorus and arsenic together, leading to the supposition that arsenic was as objectionable as phosphorus. Professor Arnold's results showed that when even $1\frac{1}{4}$ per cent. of arsenic was present, it would make steel almost good enough for boiler-plates. Why, then, should they be frightened at a few hundredths, one-tenth, or perhaps two-tenths of arsenic? On one occasion he had met with a steel containing two-tenths of arsenic, which was a very good steel. Many years ago, in his paper on arsenic in iron, he mentioned the subject, and he did not see why they should be troubled with the arsenic scare now.

There was no doubt that those specifications were preventing the importation of certain classes of ore which would otherwise be used in this country, in that way preventing progress. Mr. Harbord in his paper many years ago showed similar results to those of Professor Arnold, and that as much as $\frac{1}{2}$ per cent. of arsenic in steel did not do any more than an appreciable amount of harm; whereas $\frac{1}{2}$ per cent. phosphorus in steel, of course, would be utterly ruinous. In one of Mr. Harbord's experiments $\frac{6}{10}$ per cent. of arsenic in steel gave material which contracted at the breaking-point 54 per cent. in area. He thought, therefore, they could say that arsenic was nothing like so injurious in its effects as people imagined, and would suggest that the matter should receive most careful investigation, so as to place arsenic in its proper place.

Mr. P. C. GILCHRIST, Member of Council, said there were practically three papers to discuss, for he thought they might treat what Mr. Stead had said as another paper. With reference to Mr. Stead's remarks, it appeared at first sight that his results offered to the analyst quite a new and very important method of analysis. Hitherto, when they had reported to the managers of works the analysis of steel, they had reported 0.04 of sulphur, and had said that if it did not roll properly it ought to have done so; and that had brought them, as analysts, rather into disrepute. But supposing instead of reporting 0.04 of sulphur, they had magnified that 0.04 by 5 or 6, and reported that it contained 1 per cent. of some definite alloy of iron and sulphur; then they might be at the commencement of finding out what had caused that particular rail or plate (or whatever it was) not to roll on the one hand, or not to weld on the other. He only offered that as a suggestion to those chemists who were fortunate enough to be able to devote their whole time to analysing those interesting samples (notable failures and successes) that were sent in from the works from time to time. The two papers by Mr. Hadfield and Professor Arnold were exceedingly valuable in themselves, and still more valuable for the results and for the work which would flow from them; and the suggestion that Mr. Hadfield had made, that the Institute, or preferably its members, should offer some prize for papers,

or that they should appoint a committee to report on carbon in its different combinations with iron, appeared to him worthy of their most careful consideration. He did not suppose the funds of the Institute could be used for a purpose of that kind; it would have to be a fresh fund altogether. If the members considered the matter worthy of a trial, might they not subscribe some small sum themselves (not exceeding £5, or any less sum), and might not the subscribers themselves appoint a committee, with the President as chairman, to deal with the investigation? Possibly a committee of seven might be a convenient size. Some twenty years ago, when he was in South Wales under Mr. Edward Martin, he had the advantage of studying the metallurgy of copper and iron. In those days they were clever enough to make and also to roll (a compound of iron and sulphur) into a rail a metal that contained as much as 1 per cent. of sulphur. It was peculiar stuff, although it made a very fair rail. At that time he was unable to find out what was the cause of certain failures, and he wrote to Dr. Percy, under whom he had had the privilege of studying. Dr. Percy very justly pulled him up, and told him that he (Mr. Gilchrist) had not been analysing everything, and that he had better turn over a new leaf and analyse everything, *i.e.*, he must ascertain the facts in the case. What Dr. Percy said was pretty well to the effect: "First ascertain what are the facts in the case under consideration, ascertain some of these by analysis, and after all the facts are recorded and are thoroughly well established, then the necessary theories can be invented." "Remember too," he said, "it is of very little importance to the world who discovers a fact—that is, a truth; but it is of great importance that it should be published as soon as possible, so that the discoverer may repay in some very small measure the almost overwhelming debt that he owes to the labours of others."

MR. H. TOMLINSON said he had not the advantage of being a manufacturer of iron, or even of being a metallurgist. He could not claim to be more than a physicist. For the last twenty years he had been experimenting on the physical properties of iron and steel, and during the most of that time he had had almost continually before his mind the remarkable changes which took place

in those metals at certain high temperatures, and he felt that the subject was so difficult, so full of complexity, that instead of the manufacturer of iron, the metallurgist, the physicist, and the chemist sneering at each other, they should all combine their forces, for it was one of the most difficult nuts to crack that had ever appeared before the Institute. He would first say a few words in corroboration of what Professor Roberts-Austen had said, in criticising Professor Arnold's statement, that it was now generally admitted that the appearance and disappearance of magnetism coincided with the point Ar_2 . Experiments were made some two years ago by two students at King's College, under the guidance of Mr. John Hopkinson, on very nearly pure iron, iron that contained only a trace of carbon, a trace of silicon, no phosphorus, and 0.013 of sulphur. They found the magnetic change to occur at about 855° . Professor Austen and himself had made experiments on nearly pure iron containing only a trace of carbon, a trace of silicon, and 0.012 of sulphur, and they found the temperature at which the magnetic change took place to be somewhere about 837° . Mr. Hopkinson had also experimented with various specimens of iron and steel, and he made the magnetic change to range from 870° to 690° . It appeared to him (Mr. Tomlinson) that the magnetic change might be made to vary in the most wonderful manner. With pure iron they might get it somewhere, say, about 850° ; with mild steel they might get it somewhere about 750° ; and with hard steel they might get it at 650° . If iron was alloyed with 25 per cent. of nickel, they got it at about 650° ; if with 30 per cent. of nickel, they got it below $100^\circ C.$, somewhere about 80° ; and he had a strong impression that Mr. Hadfield's celebrated manganese steel might possibly be made magnetic by lowering it, if it could be sufficiently lowered, some distance below zero C. He would also like to speak, as Professor Austen had done, of the curious analogy between sulphur and iron. There were two distinct allotropic modifications of sulphur, just as Mr. Osmond believed there were two distinct allotropic modifications of iron. There was only one other point to which he would like to allude, and that was the statement made by Professor Arnold that "no element except carbon has, *per se*, the power of conferring on quenched iron the property of abra-

sion hardness to any extent worthy of consideration." He quite agreed with Professor Arnold that that might be so as regarded hardness in the mass itself, but it did not at all follow that it necessarily implied that the molecular groups were themselves not hard. His (Mr. Tomlinson's) opinion, derived from his work, was that an ordinary mass of iron consisted of groups of what the chemist would call molecules. It did not follow that there was the same number of molecules in each group, and he could not say anything about the number, but there seemed no doubt that there was that constitution. The whole group of molecules might form something exceedingly minute, something microscopic. It seemed evident from Hopkinson's experiments on the magnetic properties of iron, that when the iron had reached the temperature at which it ceased to be magnetic, the molecules which formed the group were exceedingly rigid, and required an enormous force to turn them on one side so as to show any traces of outward magnetism. He (Mr. Tomlinson) had himself formed an idea of how that might occur, and he believed it might be due to the fact that in iron they had to deal with two distinct forces, the attraction of one molecule upon another, which existed not only with iron, but with all metals. There was also the fact that those molecules were magnetic, and might exercise upon each other an enormous attractive force. Professor Hopkinson's experiments had proved that the molecules which are supposed to be in the group were intensely rigid when the iron was in the non-magnetic condition, and he (Mr. Tomlinson) believed that that would be so with Mr. Hadfield's non-magnetic steel. The question of hardness was one of great difficulty. If they took the non-magnetic steel and drew a file across it so as to make a mark, they were not necessarily invading the group of molecules itself; they were merely separating one group from another; and whether one group could be separated from the other depended upon the attraction between one group and another. What the members of the Institute were concerned with was of course mass hardness, and therefore he felt some diffidence in talking about molecular hardness; but all the same he thought it quite possible that molecular hardness might have some bearing on the mass hardness of quickly-cooled high carbon steel. He thought it quite probable that, if it were not for

molecular hardness, the mere presence of carbon itself would not suffice to produce the mass hardness.

Mr. W. GOWLAND had carefully followed the author of the paper in his account of the experimental work he had carried out—in a great measure by following the methods of Mr. Osmond and Professor Roberts-Austen—and the conclusion at which he had arrived from a consideration of the results of his experiments. The results of his researches had been ably, and, he thought, conclusively dealt with in the replies of Mr. Osmond and Professor Roberts-Austen. He would therefore confine his remarks to the first “item of inquiry,” which was as follows:—“The experimental evidence has proved beyond doubt that the ultimate physical influence of elements on iron is not in any way governed by the periodic law. If any such influence exists at all, the molecular action is so feeble that the interposition of other causes, viz., individual properties of compounds and crystalline effects, has converted the law into a series of exceptions.” The application of the periodic law deduced by Professor Roberts-Austen from his investigations on the influence of small quantities of other elements on gold—a metal the most suitable for such research, as it was so easily prepared in a state of purity—might be briefly stated as follows:—“The influence of small quantities of elements on the molecular structure of a metal is in accordance with their atomic volumes.” The author of the paper appeared to have entirely misapprehended the meaning and scope of the application of the law of periodicity as thus enunciated, and had set up for attack an interpretation of the law which it was never intended to bear, and had then proceeded to demolish his own interpretation. As had been pointed out by Mr. Osmond, all that was claimed by it was, “that the added element influences the molecular structure of the metal to which it is added according to its atomic volume,” and it had never been claimed that that influence would not be modified, or even masked altogether, by the presence of other elements, or by varying physical conditions. The very essence of the operation of such a law was that the element acting and the element acted on should both be in a state of purity. Now, however pure the acting elements might have been,

the iron acted on, in every experiment made by the author of the paper, was not pure iron, but iron containing carbon and varying proportions of other elements. Thus—

The nickel alloy contained 0.09 per cent. of manganese.

The manganese alloy contained 0.37 per cent. of silicon.

The tungsten alloy contained 0.14 per cent. of manganese.

The copper alloy contained 0.04 per cent. of silicon.

And so on, and all contained about 0.1 per cent. of carbon. So that in every experiment, at least one, and sometimes two other, elements were always present in considerable quantities, besides the element the action of which it was attempted to determine. The interference of one element with the action of another was well exemplified in the case of the metal copper. In illustration of this he might cite the influence of suboxide of copper in copper containing arsenic on the electric conductivity of the metal. When arsenic was present in copper in quantities varying from 0.25 per cent. to 5.00 per cent., the relation between the electric conductivity of the metal and the percentage of arsenic present was represented, if plotted, by a continuous curve. The electric conductivity increased regularly as the percentage of arsenic decreased; but at 0.25 per cent. of arsenic, owing to the action of suboxide of copper, the curve became a zigzag and the electric conductivity was no longer proportional to the amount of arsenic. Up to this point the effect of the arsenic had been paramount; beyond it, its effects were masked by suboxide of copper, and the law relating to the influence of arsenic on the electric conductivity of copper no longer held. Other illustrations might be taken from the metallurgy of copper, which would demonstrate clearly that if similar experiments to those made on iron by the author of the paper were made on the metal copper, containing other elements in similar proportions to those contained in the iron which he used, the results obtained would not show the tone or normal influence of any element on this metal. One characteristic example would suffice, viz., the action of arsenic on copper and on copper containing 0.1 per cent. of bismuth. It was well known that when 0.3 to 0.4 per cent. of arsenic was added to copper, the forgeability of the metal at a red heat was greatly increased. Now, if the same amount of arsenic was added to the same copper, but to which

0.1 per cent. of bismuth had also been added, the metal was not forgeable, but brittle. The bismuth having entirely destroyed the normal influence of the arsenic.

In the first illustration the normal influence of arsenic on the electric conductivity of copper was masked by suboxide of copper; and in the second, its normal influence on the forgeability of copper was nullified by bismuth. In those examples the quantity of the suboxide of copper and of the bismuth present were very small, much smaller than the amount of arsenic. So that both by the properties of electric conductivity and of forgeability the fallacy of attempting to determine the influence of an element when another was also present was clearly demonstrated. The true or normal influence of arsenic on copper could not be determined by experiments on copper containing either of the above-mentioned substances. Other elements behaving similarly might be cited, but he thought the above would suffice.

If that was true of copper, it applied with even greater force to iron, for the influence of 0.1 per cent. of carbon alone (the amount present in the iron experimented upon), without considering the other elements also present, was infinitely greater than the influence of either suboxide of copper or bismuth on the former metal, and more than sufficient to mask or destroy the normal influence of any of the elements which were the subjects of the experiments. So that the true influence of any single element on iron has not been determined by any experiment contained in the paper. Useful as the experiments might be in demonstrating the effects of the combined action of various elements on iron, they had no direct bearing on the influence of single elements on the metal, but rather only elucidated the conditions under which apparent exceptions to the application of the periodic law might occur. He thought it would therefore be admitted that the author of the paper had failed altogether to prove "that the ultimate physical influence of the elements on iron is not in any way governed by the periodic law." He had been compelled to make these critical remarks, as he thought it would be a great loss to metallurgy were the application of this law, as proposed by Professor Roberts-Austen, to cease to be a guiding theory in practical research and also in practical work.

Its full importance was not perfectly comprehended ; but it was hoped that in future by its aid more and more light would be thrown on the complexities of molecular structure. There were, of course, several anomalies in the law which required further investigation for their explanation ; but what law or theory had been free from such during the early days of its enunciation ?

Professor J. O. ARNOLD, in reply, said he was much pleased with the discussion. It had been exceedingly interesting. He had a mass of evidence, some of it of considerable weight, to meet. It had been proved very clearly, he thought, on the whole, by theoretical evidence, that the law should so act that nickel and manganese and copper should harden the iron when it was quenched. As a matter of fact, these alloys would insist on bending double. The law also proved that, theoretically, phosphorus and arsenic and sulphur should bend double when slacked out, owing to the softening influence of α iron. Unfortunately, from a practical point of view, they had snapped short. Pending a full discussion, he need only say that, to show which set of opinions would be most valuable to the Institute.

The PRESIDENT said he was sure they would agree that they felt deeply indebted to Professor Arnold for his paper. Although it was now proposed to adjourn the discussion, it would not be closed, but would be continued by correspondence, and he hoped that the paper would be very fully discussed.

CORRESPONDENCE.

Dr. JOHN HOPKINSON, F.R.S., did not think, so far as his experience went, that any general connection could be traced between the magnetic properties of iron alloys and the carbon which they contained. In the paper to which Mr. Hadfield had referred were given the magnetic properties of a considerable variety of iron alloys. It was in the first place clear that the maximum induction of the material by no means depended upon

the quantity of carbon it contained, as it was found that Whitworth steel which contained 0.89 per cent. of carbon had a high maximum of induction, higher than the induction of manganese steel, silicon steel, or chrome steel. On the other hand, it did not appear to have any definite general effect upon the coercive force, for the coercive force of the same Whitworth steel was, when not annealed low, about 8.26; whereas the coercive force of chrome steel containing no more than 0.532 of carbon was, in its hardened state, as high as 38.15. Again, in the case of tungsten steel the maximum induction was diminished with the smaller proportion of carbon, but the coercive force was materially increased. Nor did it seem that the presence of carbon could be the main cause of variations in the temperature effects; this was well illustrated in the case of alloys of nickel and iron. He had experimented on a number of such alloys (*Proceedings of the Royal Society*, April 17, 1890). No less than eight quite different samples of alloys were examined. All these had in common a small percentage of carbon, generally about 0.28, in one case no more than 0.18. There the properties appeared to entirely depend upon the proportion of iron and nickel.

The magnetic properties of the alloy containing 22 to 25 per cent. of nickel were very extraordinary. That material could exist either in a magnetisable or non-magnetisable condition; it changed from the non-magnetisable to the magnetisable at a low temperature, 30° or 40° below freezing-point centigrade, and it changed back again from the magnetisable to the non-magnetisable at a temperature of about 600° C.; and in each case having changed, it remained until it was brought to the other temperature. The density of the material was 8.15 when non-magnetisable, 7.99 when magnetisable. The electrical resistance too was quite different in the two states. If a wire of this material in its non-magnetisable condition was broken by tension, it was found to change from the non-magnetisable to the magnetisable state. The mechanical properties in the two conditions were quite different; in the non-magnetisable condition the breaking stress was about 50 tons per square inch, and the elongation about 30 per cent., whereas in the magnetisable condition the breaking stress was about 80 tons per square inch, and the elongation about

8 per cent. The properties of this material were to his mind exceedingly instructive, and might serve as a guide to the direction in which experiments should be made upon other magnetic substances. He did not touch upon the question of the hardening of steel, as upon this he did not feel that he had any special competence to speak.

MR. H. C. JENKINS remarked that the author had done the service of making up a series of test bars, using as a base a sample of commercial iron of an exceptional degree of purity. The results of the tests of such a series were of much value, but they would be still more valuable if the author would state whether the figures were obtained from single bars or as the mean results from several bars; and if the latter was the case, in what degree did the extreme results differ from the mean. The rate of loading during the tensile test was also important and should be maintained rigorously the same throughout the series of experiments, but the author had not stated whether this was done. The type of machine that the author employed for his tests was one pre-eminently adapted to maintain a fixed rate of loading. But the tensile and other mechanical tests did not throw much light on the α and β theory of the constitution of steel. The terms "hardness" and "softness" must not be confounded with the degree of resistance to abrasion nor with ductility. If the author would take a bar of pitch and submit it to his bending tests, he would get results that wholly depended upon the rate at which he applied the load. If applied rapidly the bar would be sharply broken off, whereas if he allowed some considerable time to be occupied by the experiment, the bar would bend double under a stress but little more than that due to its own weight. It was indeed very *brittle*, or the rate at which it underwent deformation without fracture was very slow, but the bar nevertheless was very *soft*, and a small stress permanently deformed it.

The terms hardness and softness had to do, in the theory under question, with *molecules*, and no mechanical tool had as yet shown any more than the average grip the molecules exercise upon one another. If the grip was very strong, then the material was capable of resisting abrasive influences; but the molecules might be

widely different in two cases and yet grip one another similarly in the average. An allotropic change, such as a concentration of the molecules into a series of larger groups, would, as Osmond had pointed out, tend to increase the distance between the centres of the groups and diminish the average attraction, and that would alter the power of the body to resist abrasion. Fortunately there were at command other means than mechanical ones, by which the molecules may themselves be tested for molecular hardness or *rigidity*. Notably amongst those might be named the stress due to a magnetic field.

The author mentioned his failure to obtain iron in combination with boron. Professor Roberts-Austen had some time ago suggested boron steel to him (Mr. Jenkins) as an interesting subject. The research was in progress, and he hoped to be able shortly to lay before the members of the Institute some interesting results. But he found no unusual difficulty in the preparation of boron steel, though it must be confessed that more favourable modes of introduction of the elements the one to the other were in vogue at South Kensington than the exceedingly coarse one described by the author in his paper. Boron steel appears to have many of the characteristics of carbon steel. And here the question might be asked, Why did electro-iron resemble "hardened" steel? Was it not that probably the hydrogen performed the same function as the carbon?

The author put much stress upon the change in micro-structure that he saw in specimens heated to 650°C. , 750°C. , and 850°C. respectively. His observations were however inconclusive, since any complete molecular change would cause a correspondingly complete disorganisation of the original structure, and if several changes had taken place successively then the *last* of those in the order of cooling would be the one always seen. Molecular change would indeed involve a change in the quasi-crystalline condition, although the converse of this would not be necessarily true. The crystallisation point referred to by Mr. Osmond seemed rather to be that known to every tool smith, and occurs at 800° to 1000°C. It agreed more nearly with the point noted by Dr. Ball, and must not be confounded with the $\alpha\beta$ change.

It was a useful thing to have a theory, and to keep it until a

better was obtained, provided always that it was remembered to be a theory. The $\alpha\beta$ theory of the hardening of steel gave carbon a prominent place, viewed as a frictional resistance to certain changes. That agreed well with the facts known to every practical man, such, for instance, as the tempering of hardened steel, which was as much a function of time as it was of temperature.

Mr. ANDRÉ LE CHATELIER was of opinion that Mr. Hadfield's most interesting results, despite the completely novel indications which they afforded as to the properties of iron, did not disprove the existence of the allotropic modification of iron, described under the name of β iron. While being convinced that the hardening effect produced on carbon steel by plunging into water was not due to the presence of β iron, he still believed that β iron exists in the non-magnetic manganese steel as well as in non-magnetic ferro-nickel containing 25 per cent. of nickel. Strictly speaking, one might admit that the increased electrical resistance and the absence of magnetism which characterised those two alloys were only due to changes in the state of the carbon. There were, indeed, numerous proofs that the electrical and magnetic properties of metals might be influenced in a very marked degree by a very small quantity of foreign substances. Thus traces of oxygen sufficed to considerably diminish the electro-conductivity of copper, and it might therefore be admitted that a change in the state of the carbon, or a modification of the combinations that it formed with steel, might modify its electrical resistance and even render it non-magnetic. But it was not the same if another physical property of metals is considered—the co-efficient of expansion. There was no instance of the co-efficient of expansion of a metal being largely influenced by a very small quantity of foreign matter. Traces of oxygen, for instance, did not in the least affect the co-efficient of expansion of copper. It did not therefore appear possible to explain, simply by the action of carbon, the fact that the co-efficient of expansion of the non-magnetic alloys of iron was almost double that of carbon steels. According to measurements made by Mr. H. Le Chatelier, the co-efficient expansion of steel with 14 per cent. of manganese was about 0.00002. Mr. André Le Chatelier has measured the co-efficient in the case of the magnetic and non-

magnetic ferro-nickels containing 25 per cent. of nickel. He obtained the following results:—

The magnetic alloy	0.0000119
The non-magnetic alloy	0.0000215

The magnetic alloy had been obtained by Mr. H. Le Chatelier by heating the non-magnetic alloy in a current of hydrogen, and it had the same composition as this one with the exception of the very small percentage of carbon that it might have lost during the heating. The fact that two alloys which do not differ except by a slight difference in the percentage of carbon had co-efficients of expansion one of which was double the other, could only be explained by an allotropic modification affecting the whole mass of the metal, and consequently appearing to prove the existence of β iron.

In other respects Mr. Hadfield's results were not in opposition to Mr. Osmond's theories. They showed that the effect of prolonged heating consisted essentially in that a considerable portion of the carbon passed into the condition of graphite, and being dispersed through the metal, but not combined with it, did not affect its properties. But according to Mr. Osmond's theories the effect of the carbon was to tend to maintain the β iron stable at ordinary temperatures, and it was in conformity with this theory that if by prolonged heating the proportion of carbon combined with the iron was diminished, the β iron ceased to be stable and the metal became again magnetic. In confirmation of the preceding remarks, it would be of interest to measure the co-efficient of expansion of the magnetic manganese steel prepared by heating the same alloy in its non-magnetic form. The co-efficient obtained ought to be practically equal to the carbon steels.

The β iron as it existed in the non-magnetic alloys of iron was not, properly speaking, hard. Its alloys had indeed a very low elastic limit, and were very easily deformed. Thus, whilst the non-magnetic ferro-nickel wire had an elastic limit of 130 kilogrammes, with a breaking stress of 140 kilogrammes and 10 per cent. elongation, the same alloy in its non-magnetic state had, after tempering, an elastic limit which was almost nil, and a breaking stress of 60 or 80 kilogrammes with 50 or 60 per cent.

elongation. It exactly resembled a bronze with 10 per cent of tin from the point of view of its mechanical properties. In every case it was much less hard than the magnetic ferro-nickel. It was probably the same in the case of the manganese steel.

The fact that the β ferro-nickel was not so hard as the α ferro-nickel was a good proof that it was not the β iron which was the cause of the hardness in hardened steel. Nevertheless, that allotropic modification of iron appeared to play an important part in the hardening process, although it did not exist in hardened steel. A hardened steel was not only hard and but slightly deformable, but very intense internal strains were produced by the hardening, and these manifested themselves sometimes by cracks or even by the rupture of the specimen. These strains, however, either did not exist or at least were but very slight, if a steel was hardened which had not been heated above 700° , while they had all their intensity if the metal was heated to about 850° . They were therefore not solely due to the rapid cooling of the specimen. Mr. Osmond's experiments showed that the temperature at which the transition from the α state to the β state was normally produced on slow cooling was lowered in the case of rapid cooling, the action increasing with the rapidity of cooling.

Let us suppose a case in which the cooling was sufficiently rapid to lower this temperature by some 400° . During this interval of 400° the metal, having remained in the β form, would have a high co-efficient of expansion, somewhere about 0.00002. It would then be much more contracted than if the cooling had been slow, for in this latter case it would have been in the α state, and would have had a lower co-efficient of expansion. It follows that in the case of rapid cooling there was a moment of considerable expansion when the β form passed into the α modification, which might reach even 2 or 3 millimetres per metre, and as this did not take place simultaneously on the outside and on the inside of the metal, which were cooled with different degrees of rapidity, it necessarily followed that considerable internal tensions resulted, which sufficed to explain the strains which existed in hardened steel. The hardening effect produced by these internal strains should also be one of the causes of the hardness which was observed in the metal after sudden cooling. It was probable that the changes which the

compounds of carbon with iron experienced as a result of this cooling were not the sole cause of the hardening. Indeed one might harden any steel in this way, however low might be its percentage of carbon. Thus in cooling suddenly a wire of extra mild steel, with only 0.06 per cent. of carbon, and with a resistance to tensile stress of only 21 tons per square inch, he (Mr. André Le Chatelier) had obtained a tensile strength as high as 60.3 tons without appreciable elongation. Such an augmentation of the hardness could not be explained merely by the influence of so small a quantity of carbon.

With a view to verify the exactness of the preceding points, it would be very interesting to study the variations in volume which occurred during the cooling of steel. It was probable that in employing a highly carburised steel, in which the temperature of transformation studied by Mr. Osmond experienced a marked lowering even with a not very rapid cooling, interesting observations might be made.

The chief reason which had caused Mr. Osmond to admit the existence of β iron in hardened steel was that the evolution of heat, which corresponded in slow cooling to the passage of the β to the α form, had become attenuated, and finally disappeared as the cooling became more rapid and as the temperature of transformation was lowered. But as, in accordance with the preceding remarks, the expansion, which was produced at the moment of this change was the more pronounced as the corresponding temperature was lower, it followed that the evolution of heat must be less and less pronounced. The heat that was necessarily absorbed by the very fact of that expansion must be taken from that which was produced by the allotropic change of β into α iron.

Professor H. LE CHATELIER was of opinion that the method of observing the arrests on cooling and on heating was insufficient to elucidate the question of the allotropic transformation of iron. It could only serve for a preliminary qualitative study of the general phenomena which occurred during the heating of the metal and for an indication of the direction in which more precise experiments were necessary. Indeed the results obtained by that method depended on two entirely distinct kinds of phenomena :—

(1.) The molecular transformations intended to be studied.

(2.) The delays in those transformations analogous to those which were shown in nearly all chemical changes (supersaturation, surfusion, slow combustion).

It was known that the rapidities of chemical reactions, and consequently of the delays in the completion of those reactions, were influenced by so large a number of conditions that it had hitherto been impossible to assign to them any precise law. There was therefore very considerable interest attached to the study of the changes of iron, in eliminating the influence of these delays in the transformations which were the principal causes of the irregularities in the results obtained. For that purpose it was necessary to characterise the different states of iron by certain of their properties which might be measured at constant temperature, which enabled time to be given for the completion of the transformations.

The three most suitable of these properties appeared to be :—

The linear dimensions.

The electrical resistance.

The magnetic properties.

It did not seem as if the mechanical properties (strength, elongation), the measurement of which was equally possible at every temperature, would be suitable, because they were to a considerable extent dependent on the *structure*, that was to say upon quite a different kind of phenomenon from the molecular changes.

It was not possible to be contented, either, with any one of the three properties mentioned, in view of various difficulties which were inherent to the study of each of these. It would be necessary, in order to arrive at a definite result, to bring together the various results relating to each of those three categories of properties. The difficulties referred to were the following :—

The changes in length were very slight and were consequently difficult to measure. Moreover, a bar of metal that had been heated never, after cooling, resumed exactly the original dimensions.

The electrical resistances were considerably influenced by the presence of traces of impurities, in consequence of the cellular structure of metals. It was necessary to distinguish what properly

belongs to the metal, and an interpretation of the results submitted to discussion was thus afforded.

The magnetic properties gave rise to phenomena which were very complex and difficult to interpret on account of the variations in the results, according to the intensity of the magnetic field employed.

Mr. Le Chatelier thought that the only changes, the existence of which had been definitely established, were the following:—

(1.) The recalescence or change of the carbide of iron at 700° , as to which every one was in accord.

(2.) The change of iron at 735° , Osmond's point AR2, corresponding to the loss of the magnetic properties and to a marked change in the law of the increase of the electrical resistance, a sudden alteration that he formerly wrongly attributed to recalescence.

(3.) The change of iron at 850° , Osmond's point AR3, the existence of which, despite the contrary opinion of Mr Arnold, appeared to him to be proved by a second and still sharper change in the law of the variation of the electrical conductivity. It also corresponded to a second slight change in the magnetic properties.

(4.) The change of iron at 1280° originally pointed out by Dr. Ball, and definitely shown to exist by Mr. Curie by measurements of the magnetic properties.

With the two points at 735° and 850° , there corresponded in the case of nickel the point at 340° which was marked by the loss of the magnetic properties and by the change in electrical conductivity.

As regarded the new point at 950° pointed out by Mr. Arnold, the question might be asked as to whether this may not be a point of fusion of a sulphide of iron. Phosphoric pig irons showed a similar point, which corresponded to the fusion of a phosphide.

The several changing points of iron appeared to remain invariable in the presence of metalloïd impurities; carbon, sulphur, silicon, &c., &c. That would follow from the investigations concerning the electrical conductivity. On the contrary, however, the delays in the change might vary considerably owing to the presence of foreign substances, as was shown by the results of experiments by heating or cooling.

Inversely these points of change were displaced, as was proved

by the study of the electrical resistances, when isomorphic metals such as nickel and manganese were added to iron. The points proper to each of these two metals were replaced by an intermediate point, the temperature of which depended on the proportion of the mixture. That difference of action was moreover a necessary consequence of the theory of the cellular structure of steel. The metalloids placed themselves in the walls of the cells, while on the contrary the metals mingled in a uniform manner with the iron which forms the interior of the cells.

He was completely in accord with Messrs. Arnold, Hadfield, and Howe in admitting that in the hardening of ordinary steels it was the carbide of iron alone of which the change was preserved, but he thought, on the contrary, that in manganese steel and in ferro-nickel, non-magnetic substances of great electrical resistance, that it was one of the two allotropic modifications of iron normally stable at elevated temperatures that was preserved.

Professor A. LEDEBUR thought that on account of the numerous experiments described in it, Professor Arnold's paper formed a valuable addition to scientific knowledge, even if the dispute over the α and β theories were entirely disregarded. Hitherto those theories had not found many supporters in Germany. The atomic volume theory, however, appeared to him to be entirely unsupportable, if he properly understood it. He had always found that the purest metals—the purest iron, the purest copper, the purest gold, &c.—showed the least hardness and the least degree of brittleness, while they were the most ostensible, and that in every instance the hardness was increased by the absorption of a foreign substance, the extensibility being at the same time diminished, more by the one substance and less by another. That iron showed a tendency to become soft and malleable by the presence of phosphorus was entirely opposed to all observations. A very small percentage of phosphorus might, it was true, increase the tensile strength of iron if the stress was applied steadily, but the hardness and the brittleness always increased as well.

Mr. Hadfield's interesting observations were well suited to induce further investigations. He agreed with him in the belief that the curious behaviour of manganese steel depended on the

formation of carbides, and on their decomposition if the conditions changed, but the proof of that was still wanting. If the piece of malleable cast iron, to which Mr. Hadfield referred, contained after heating and hardening, less graphite or temper-carbon than it did previously, it appeared to him to be an additional proof that graphite and temper-carbon were two different modifications of carbon. True, graphite would scarcely have passed into the combined form by a heating which was not accompanied by fusion. It must be considered to be still undecided whether the temper-carbon, like graphite, was contained in iron as self-existent separated carbon, or as a component of some carbide, rich in carbon, visible to the eye on the fractured surface, and which was decomposed with the deposition of insoluble carbon when the iron was dissolved in acids. The latter view appeared to him to be the more probable. There was still a wide field for investigation in that direction, as Mr. Hadfield pointed out.

Mr. H. LOUIS thought that it was impossible to study Professor Arnold's elaborate and comprehensive paper without being struck by the large amount of valuable information which it contributed to the knowledge of the physical characters of steel, and its importance from that point of view could not well be over-rated. The real object of the paper, however, was to controvert two theories respecting the physical properties of iron which had recently been enunciated, and it was accordingly important to examine the paper in its polemical aspect so as to see how far this object had been attained. He personally considered it a matter for regret that Professor Arnold had seen fit to deal in one paper with two quite independent theories, which had nothing in common but their sponsors, and the truth or falsity of either of which might be demonstrated without in any way affecting the position of the other. The two theories were: firstly, that elements influence the physical properties of iron in accordance with the periodic law, and secondly, that iron was subject to allotropic modifications. Respecting the former theory, he had no doubt that even Professor Roberts-Austen was far from claiming that the law which he had enunciated, had been irrefragably established; it was at present in the position of a workable hypothesis which required either fuller

proof or definite disproof. Professor Arnold had attempted to investigate this theory by preparing a series of alloys of mild steel (*not iron*) with about 1.5 per cent. of various elements and then examining the physical effects produced by these elements on their respective alloys. His mild steel contained about 0.1 per cent. of carbon on the average; upon the very rational assumption that this carbon was present as normal carbide of iron (Fe_3C), these alloys would contain on an average about 1.5 per cent. of this carbide, or just as much of the carbide of iron as there was of the foreign element introduced by Professor Arnold. Yet that gentleman entirely overlooked the effect of the former substance, and ascribed all the variations in physical properties to the latter element only. It was, however, quite possible and indeed probable that the effect of any element upon mild steel, containing an amount of carbide of iron equal to that of the element introduced, would be very different to the effect of the same amount of that element upon pure iron. It would obviously make a great difference whether the element introduced had the property of decomposing this relatively large percentage of carbide of iron and itself forming a carbide, or whether a triple alloy be formed of the element with iron and carbide of iron. No attention had, however, been given by the author to this undoubtedly difficult problem, in spite of its vital importance to the question at issue. Moreover, in addition to carbon, the steel employed always contained other impurities, sometimes in notable proportions, and their effect too had been disregarded; it had yet to be proved that they had none at all. Whatever theoretical inferences Professor Arnold might therefore feel himself entitled to draw from his experiments, he (Mr. Louis) ventured to think that he had not advanced any practical proofs that could be in any way said to have upset the periodic law theory. There was only one way in which this could be done, namely, by alloying *pure* iron with the various *pure* elements to be investigated in varying but always small proportions, and then examining all the physical properties of the alloys so produced. Until this was done the question could not be looked upon as finally settled one way or another. No doubt such an investigation was attended with enormous—perhaps all but insuperable—difficulties, but the fact that such experiments in their perfect

form presented great difficulty did not warrant drawing definite conclusions from obviously imperfect ones.

Secondly, with respect to the allotropy of iron, the hypothesis which Professor Arnold attacked was a twofold one. It stated, firstly, that iron was capable of assuming allotropic modifications above a certain temperature, and secondly, that certain elements had the power of retaining it in that state when cold. If he understood the paper correctly, the author did not attack the latter proposition—the more vulnerable portion of the hypothesis—because he simply denied that iron was capable of assuming any allotropic condition. The strongest evidence adduced in favour of such allotropy was the occurrence of the so-called critical points of temperature at which there was absorption or evolution of heat when iron was heated or cooled slowly; these critical points, or at any rate the two upper ones AR2 and AR3, were supposed, according to the allotropic theory, to indicate a change in allotropic condition. Professor Arnold now suggested that the upper point was due to a chemical change, and that the lower one, AR2, was due to the change from the plastic to the crystalline condition. There was really but one way of proving whether any of these points were connected with chemical changes, and that was by operating upon samples of perfectly pure iron; if such iron showed the point AR2, then that point could not be due to chemical action. Professor Roberts-Austen asserted that he had tried that experiment and had proved the existence of that point in iron of a very high degree of purity. Professor Arnold's rejoinder was that the purest iron which he himself used contained 0.15 per cent. of sulphur; he (Mr. Louis) failed to see how Professor Arnold's experiments with impure iron affected the results obtained by Professor Roberts-Austen with iron of a far higher degree of purity.

No one appeared, however, to have shown conclusively what was the real physical meaning of the critical points AR2 and AR3, and in so far the allotropic theory was incomplete. If, however, both these points occurred in pure iron, they must be evidence of allotropy. Professor Arnold's suggestion that AR2 marked the passage of iron from a plastic to a crystalline condition was, if well founded, further strong evidence of allotropy. In experi-

menting upon another metal he (Mr. Louis) had recently found that allotropic changes did not always occur abruptly, but that they required time for their completion. Was it not possible that the points AR2 and AR3 marked the commencement and the completion of an allotropic change—the destruction of one form of molecular arrangement and the building up of another, whilst in the interval the substance was in an amorphous condition, or else in some transition stage in which it might act like an amorphous body? He merely ventured to put forward this tentative suggestion as a possible explanation or partial explanation of the observed phenomena, although he himself still saw many difficulties in the way of its adoption.

The fact that the magnetic power of iron was strongly affected by heat, and that the most sharply marked variation of this property was exhibited at a temperature which appears in different cases to fluctuate between AR2 and AR3, was possibly a further proof of allotropic change, but at the same time, in the present state of ignorance of the real nature of magnetism, it would seem premature to assert that these variations in magnetic power must be due to allotropy. It was surely quite possible that they might be due to dynamical causes dependent on the mode of motion of the particles of the substance rather than on the structure of the particles themselves. At any rate the observed magnetic phenomena appeared to be in no wise inconsistent with the theory of allotropic modifications.

The only point that seemed clear to his mind was, that if these critical points AR2 and AR3 occurred in pure iron (and Professor Arnold had assuredly not proved that they did not), then they must correspond to an allotropic rearrangement of the atoms or of the molecules of the metal, as chemical action would be out of the question. That, however, was just the point which Professor Arnold's paper left untouched, and in spite of the great value of the data there accumulated by him as a contribution to the scientific study of mild steel, he (Mr. Louis), without holding that the allotropic theory was as yet firmly established, could not avoid the conclusion that Professor Arnold had left the question of the existence of allotropy in iron exactly where he found it.

Mr. OSMOND, in discussing Mr. Hadfield's paper, stated that Mr. Hadfield had been so kind as to send him a bar of his manganese steel, which was magnetic at one end and non-magnetic at the other. Mr. Hadfield had also sent samples of the same metal which had been annealed in oxide of iron, the method usually adopted in the manufacture of malleable cast iron. Microscopical examination of these samples showed :—

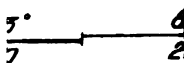
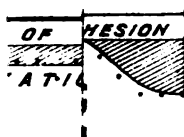
1st. That the magnetic manganese steel which had been submitted to the cementation process contained three constituents, one of which presented the ordinary characteristics of the hard constituent of cementation steels (the cementite of Howe).

2nd. The non-magnetic manganese steel, cemented and forged, only contained two constituents, one of which, the cementite, was much altered, and appeared to be approaching mechanical disintegration and chemical solution.

3rd. The manganese steel, annealed in oxide of iron, showed a superficial zone, which was a mixture of metal and cinder. The interior appeared, when polished, to be homogeneous, but the attack with acid under suitable conditions revealed groups of parallel lamellæ, which remained white on a strongly coloured field.

These facts showed that the three metals in question were complex mixtures. As the chemical composition and the magnetic or other properties of each constituent were unknown, it was naturally impossible to deduce from the mean properties and composition of the mass, any conclusion for or against this or that theory. He much regretted that he had not been informed that Mr. Hadfield intended to present a paper to the Institute on this question at the present meeting, or it would have given him great pleasure to have hastened his examination of the specimens, and to have communicated the result sooner to Mr. Hadfield, and thus have saved him the trouble of drawing premature deductions from his experiments, which were both curious and suggestive.

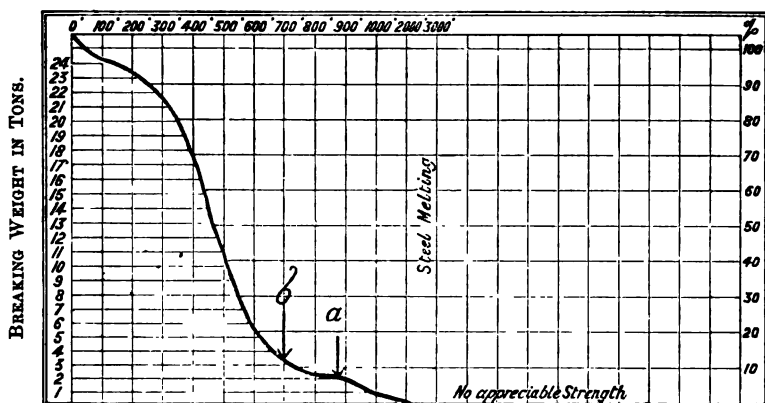
Mr. B. H. THWAITE pointed out that some years ago he ventured to suggest that the cause of the phenomenon known as recalescence was due to thermo-dynamic effect, or to the conversion of heat into work, and *per contra* to the development of heat by work. In the example where the metal was gradually reduced in tempe-



perature, there was a certain range of temperature in which molecules gradually close on each other; the internal stress set up by irregular cooling, and the abrasion of the surface of the molecules under such irregular cooling influences, must, when the heat required to effect such stress effort was absorbed, and on the cessation of such internal dynamic action, produce what was only an apparent evolution of heat. In fact, the degree of recalcence was the degree of physical or dynamic effort. It would be seen in the

Diagram showing the Depreciating Effect of Heat on the Ultimate Tensile Strength of Iron deduced from the Results of Dr. Kollman's Experiments.

TEMPERATURE UNITS IN CENTIGRADE DEGREES.



To reduce the Centigrade Degrees to the Fahrenheit Scale multiply by $\frac{9}{5}$ and add 32.
 α , Point of recalcence. β , Point of recalcence.

accompanying diagram showing the increase of tensile strength as the metal becomes solidified on cooling, that the point of commencement of a sudden increase in the strength was identical with the α point of assumed recalcence, and that the β point was identical with the second point of commencement of great thermal increase. If it was accepted that there was an absorption of heat in the directly physical work of overcoming molecular attraction, abrasion, and cohesion, the explanation of the so-called recalcence periods was clear. The Le Chatelier pyrometer could and did indicate directly the fall or rise of sensible temperature, but it

could not show the heat absorbed in doing physical work. The so-called recalescence phases merely recorded the fact that at this time there was a momentary repose in dynamic work, and no heat therefore was being expended in doing physical work, so that consequently there was a sudden but merely apparent rise of sensible temperature, equivalent to the amount of heat that had been absorbed in doing the internal, physical, and molecular work immediately prior to the period of so-called recalescence. He had ventured to correlate the points of repose in physical work of metallic solidification, and identical with an apparent rise of sensible heat—and known as recalescence,—with the changes of physical strength due to fall of temperature, or, *per contra*, rise of the temperature of the metal,—using the results of Kollman's investigations, and fixing the points of repose, or so-called recalescence phases, as determined by Le Chatelier's pyrometer. It would be noticed that the phases of recalescence were identical with a sudden change in physical strength. It would be interesting if a careful investigation were instituted, using test bars of nearly identical composition, to ascertain more closely than a purely synthetical comparison could do, the influence of the recalescence ranges of temperature on the physical character of the metal. That investigation would, he thought, prove that the author's contention that the repose periods in the action of solidification are identical with the evolution of sensible heat, and known as recalescence periods. Practical metallurgists have long recognised that the all-powerful cause of the hardening tendency was due to the influence of carbon, but they would be glad to hear this recognition confirmed by the results of Professor Arnold's investigations. He should like to hear the points of recalescence determined with a tubular test-piece so heated and cooled that the inner surface was cooled before the outer one. He believed that it would be found in these examples that the temperature range of recalescence would be considerably reduced. The intermolecular stress due to the molecular tearing away from the rigid shell of cooled metal that enclosed a volume of hot and unsolidified metal must be very great, and during the development of these strains the absorption of heat for dynamic work must be considerable. In order to more clearly elucidate the theory he advanced to explain the so-

called recalescence phenomena, he had attempted to show its application by a graphic diagram, giving the curve lines of sensible temperature of a heated and of a cooled bar of almost ferro-purpure iron, and as determined by Professor Arnold. In these graphic diagrams (Plate XXVII.), the hatched portions showed the amount of heat hypothetically allocated by him as having been absorbed in effecting physical work *per se*. The points of the so-called recalescence, or when there was a momentary cessation of heat absorption in thermo-dynamic work, and the full heat value was at once left as sensible and measurable by thermometry, are marked respectively "points of repose" A, B, and C.

Mr. P. C. GILCHRIST, Member of Council, ventured to think that the bibliography given by Mr. Hadfield in his paper was a piece of excellent work, and that the library of the Iron and Steel Institute ought to possess all the books referred to both in that and in any other bibliography read before the Institute.

Dr. H. WEDDING had great pleasure in complying with Mr. Hadfield's request that he should state his views in connection with the subject of Mr. Hadfield's paper on "The Results of Heat Treatment on Manganese Steel, and their Bearing on Carbon Steel." He (Dr. Wedding) considered that it was not yet possible to state definitely what was the exact cause of the magnetisability of iron. The question propounded by Mr. Hadfield was based on the doubt whether the magnetisability of iron was dependent or not on its percentage contents of carbon and other elements, provided that the pre-existing working conditions were identical; or, in other words, if the heating, cooling, and mechanical treatment had been carried out under precisely identical conditions. If the magnetisability of iron was independent of the foreign constituents it might contain, in their various modifications and proportions, then Osmond's assumption that there exist various modifications of the iron itself must of necessity be accepted. On the other hand, if the magnetisability of the iron was dependent on these constituents, it became unnecessary to assume the existence of various modifications of iron. As was proved by the experiments described by Dr. Z. Holborn,* and carried out at the Imperial Physico-Technical Institution at Charlottenburg, near Berlin, the

* *Zeitschrift für Instrumentenkunde*, vol. ii. 1891, pp. 113-124.

influence which was exerted by slight variations in the temperature was remarkably large in the case of iron containing small quantities of carbon. If in conjunction with this it was also remembered, as he (Dr. Wedding) endeavoured to show, so far back as 1889,* that the structure of iron, visible under the microscope, changed considerably when iron containing carbon was heated even to only 210° C., the conclusion was not far-fetched that the arrangement of the ultimate particles of which the iron was composed was sufficient to account for its varying degree of magnetisability, and that the assumption of several modifications of iron was unnecessary.

It would be remembered that Werner von Siemens recognised the magnetisability of iron by the arrangement of its particles (textural constituents or crystalline parts) in a direction parallel to an electrical current. It was well known that a piece of iron which was suspended in the line of the magnetic meridian became magnetic in the course of time. At ordinary temperatures this sometimes only occurred after the lapse of years. Indeed, even at ordinary temperatures, the particles of the iron changed their relative positions until their axes became parallel to the magnetic meridian, under the feeble action of the earth's magnetism. The electrical current overcame the resistance of the cohesion with the greater readiness, the greater was its intensity. The more readily movable the particles were, the more easily, too, did they return to their original position, or to that dependent on their shape or crystalline form. In soft iron this ready mobility of the particles was very considerable, and the metal therefore received the maximum degree of magnetisation easily, but lost it when the current of electricity ceased. In hardened steel this mobility was very slight. It therefore became magnetic only with greater difficulty, but it retained the magnetism firmly, and for a long time. The higher the temperature, the greater the mobility became, and hence the power of becoming magnetised ceased. It was scarcely open to question that carbon, manganese, and other elements exerted a considerable influence on this mobility. In this form of explanation, again, the assumption of different modifications of iron became unnecessary.

* *Stahl und Eisen*, 1889, p. 265.

The question propounded by Mr. Hadfield could, he thought, be solved. He had already attempted this, although, it was true, without success, as the facilities at his disposal were inadequate. None would be better adapted for this than Mr. Hadfield and Mr. Osmond in conjunction, and he should be most happy if this suggestion led to the investigation of this question, important both on scientific as well as technical grounds.

The experiments should be carried out by making a series of microscopic sections of various kinds of iron, and then, while these were being examined microscopically under a strong power, passing a current of electricity through them, while at the same time they were heated to various temperatures. In that way it would evidently be possible to obtain a clear idea of the texture, especially if their images, at their various stages, were fixed by the aid of photography.

MR. F. W. HARBORD thought that it was a matter for regret that the limited time at the disposal of the Institute prevented the more complete discussion of the extremely interesting papers of Professor Arnold and Mr. Hadfield, as many points could have been much better threshed out in the presence of the authors. Professor Arnold divided his paper into two parts, and devoted the first part to disproving the periodic law as enunciated by Professor Roberts-Austen; and the second part to discussing the existence of the hard allotropic modification of iron. He thought it would have been fairer and have made the whole matter clearer, if at the outset Professor Arnold had quoted Professor Roberts-Austen's own enunciation of the law; but as he had not done so, the following extract might be given from the discussion on the first Report of the Alloys Research Committee on October 29, 1891. In reply to various criticisms, Professor Roberts-Austen said that he considered any classification in the present state of our knowledge premature, but offered a *tentative* classification based on the atomic volume of the added impurity: he said "it showed that as the atomic volume of the added element augmented, the influence gradually ceased to be beneficial, and ultimately became absolutely prejudicial to the mechanical properties of the steel." That, then, was what Professor Arnold disputed and

devoted the first part of his paper to disprove. For that purpose he submitted a series of alloys for comparison, not containing, as one would expect, equal percentages of added impurities, but varying from 1.10 per cent. of chromium to 1.94 per cent. of silicon, and he cheerfully compared them as though they were strictly comparative, and the 0.8 difference in added elements were beneath notice. In the tensile tests he made a great point of the copper alloy containing 1.8 per cent. of copper giving a higher tensile than nickel alloy containing 1.50 per cent. of nickel. Surely it was conceivable that the addition of 0.3 per cent. of impurity other than carbon might have *some* influence on the tensile strain, and in view of the fact that not infrequently test-pieces cut from the same plate of mild steel having identical chemical composition, would vary in tensile strain as much as 2 tons per square inch, he was not surprised at Professor Arnold's results.

With regard to arsenic, he would suggest that before drawing any special deductions from a single sample, another alloy be made, as the results given were very different to those obtained by Mr. Tucker and himself when making a series of arsenical alloys from mild steel. One sample, containing about 1.00 per cent. of arsenic, was so brittle that an inch round bar falling off a table 3½ feet high on to an iron slab was broken in two. Speaking generally, they found that 0.200 per cent. of arsenic had about the same effect as 0.100 per cent. of phosphorus, although one would expect it to be somewhat less with the very pure material used in Professor Arnold's experiments. The cold bending tests given were absolutely useless, for the simple reason that the tests were not severe enough: if the arsenic, phosphorus, and sulphur alloys were excepted, the others had been submitted to a test which the hardest and least ductile was capable of withstanding, and it was obvious therefrom that the most ductile samples must withstand it too. It was clearly proved, by the table of tensile tests, that the alloys varied in hardness; and that was confirmed by the note that the manganese and silicon alloy showed more stiffness than others. Had those tests been made on 1-inch bars instead of ¾-inch, probably most of the first seven samples would have broken before 100°, and some information would have

been obtained. The samples did not bend through 180° because they were all alike, but because Professor Arnold's method of testing was not delicate enough to discover the differences between them. It might have been of service if, in addition to crushing tests, the hardness of all the samples had been determined by Turner's method. The great objection, however, to the whole series of tests of the samples was the very unequal percentages of the added element present in the alloy. He quite realised the great amount of work involved in preparing the samples submitted, and the almost insurmountable difficulties in preparing a series containing, say, 1.00 per cent. of each constituent, and not varying more than 0.100 per cent. in such constituents, but he submitted that until Professor Arnold did prepare such alloys, he was not entitled to make any sweeping generalisations. In so far as these experiments proved anything, they seemed to him to have practically proved what the author started to disprove, as was shown by comparison of Professor Roberts-Austen's Atomic Classification given in the Reports of Alloys Research Committee. This classification, together with deductions from Professor Arnold's experiments for comparison, was appended.

RESULTS DEDUCED FROM PROFESSOR ARNOLD'S EXPERIMENTS.

1. *Carbon*.—Necessary for effecting change of iron into steel.
- Boron*.—Declined to be experimented upon.
2. *Nickel, Manganese, Copper*.—Distinct increase in tensile strain, and corresponding reduction in elongation and reduction of area, &c., the variations in tensile strains being due more to different percentages of nickel, manganese, and copper, than to special action of elements *per se*.
3. *Chromium Tungsten*.—Slight increase in tensile strain; little or no reduction in area or elongation.
4. *Aluminium, Silicon*.—Slightly higher tensile and less reduction, &c., than chromium and tungsten, but fully accounted for by containing nearly 2.00 per cent of alloy elements against 1.10 per cent. and 1.4 per cent. respectively of chromium and tungsten.
5. *Arsenic, Phosphorus, Sulphur*.—Distinctly prejudicial.

1894.—i.

PROFESSOR ROBERTS-AUSTEN'S TENTATIVE ATOMIC VOLUME CLASSIFICATION.

1. *Carbon, Boron*.—Necessary for effecting change of iron into steel.
2. *Nickel, Manganese, Copper*.—Useful under certain conditions:—Nickel in Schneider armour plates; manganese in Hadfield steel; copper in special Schneider steel.
3. *Chromium, Tungsten*.—Useful in certain conditions, but rather by exerting reflex action on carbon than by direct action of their own.
4. *Aluminium, Silicon*.—Useful as reducers but without MUCH direct action.
5. *Arsenic, Phosphorus, Sulphur*.—Prejudicial in all cases.

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Turning to the second part of the paper dealing with the α and β iron theory, the most vital point unquestionably was whether electrolytic iron chemically pure presented the point Ar3. In order to prove that it did not, the author prepared a sample contaminated with such an amount of sulphur that his results were worthless. That was the more to be regretted when, as had already been pointed out during the discussion at the meeting, he could without any great difficulty have obtained iron free from sulphur by deposition from the chloride. One could not help agreeing with Mr. Hadfield that it was a matter of disappointment that the β iron had yet been isolated, and that there were many matters to be cleared up before the hypothesis so ably advocated by Professor Roberts-Austen and Mr. Osmond could be raised to the position of an established theory. If, however, that hypothesis did not explain all the facts, it had served, and was still serving, a most useful purpose in directing the attention of scientific and practical men to the physical side of research in iron and steel as apart from the purely chemical. By that alone it had more than justified its existence.

Dr. J. A. FLEMING had read with great interest Mr. Hadfield's valuable paper, and had received from that gentleman specimens of the bars of 12-13 per cent. manganese steel which had been rendered partly or wholly magnetic by heating in a cementation furnace. A very careful examination of the physical changes undergone by such alloys as this manganese steel in passing through ranges of temperature which influence so greatly its magnetic qualities, seemed to be an especially important work. He had examined somewhat carefully, in conjunction with Professor Dewar, the changes in specific electrical resistance experienced by this steel throughout a range of temperature from 200°C . to $+200^{\circ}\text{C}$. They found that the curve of resistance-temperature had a very marked concavity upwards, a characteristic of all the magnetic metals, and that moreover it had a sharp change of curvature at about -40°C . At that temperature there was a marked sudden increase in the temperature co-efficient of the metal. It was highly advisable to investigate carefully the magnetic behaviour of manganese steel at this temperature, and he hoped before long

to be able to undertake it. The very high specific electrical resistance of this alloy made it especially useful for resistance coils for absorbing power where a very small temperature coefficient was not absolutely essential. Manganese steel had a volume specific resistance which in C. G. S. measure was about 67,000 units. This was more than seven times as great as iron. In other words, the addition of the 12 per cent. of manganese made the manganese steel as much greater in volume specific resistance than iron as iron was greater than copper. He had found that manganese steel, which could now be procured from Messrs. Hadfield in the form of wire, was a very valuable acquisition in the electrical laboratory. Manganese steel in strips could be employed with great advantage for the construction of resistances for testing dynamos and transformers, and its high specific resistance and melting-point made it very valuable for such purposes.

Dr. F. C. G. MÜLLER thought that the mechanical part of Professor Arnold's valuable paper was of great interest to practical metallurgists. It was to be regretted that many authors used the term "hardness" in the sense of "brittleness," or even in that of "strength," although these words denoted three entirely different contentions. Sealing-wax, for instance, was brittle, not hard. The presence of copper in the interesting iron alloy investigated by Professor Arnold increased the tensile strength, but it was never a hardening constituent. A substance was hard which could not be scratched by a splinter of glass or of quartz. It was brittle if it did not exhibit elongation, or if it shattered under a hammer. The only hardening element in steel was carbon. Perhaps, however, phosphorus and manganese, up to 5 per cent., also had that action., Sulphur, on the other hand, exhibited brittleness but not hardness. A good file scratched quartz, whilst the end of the file would scratch only fluorspar. Hadfield's low manganese steel was harder than apatite, but less so than plate-glass or than felspar. He would urge, therefore, that the word hardness should be used exactly in the same sense as in mineralogy.

Mr. Hadfield's interesting paper induced him (Dr. Müller) to make closer investigation of that remarkable metal. He had in his possession a small sample of manganese steel, presented

to him by Mr. Hadfield on the occasion of a visit to his works six years ago. Although his research was not yet complete, some of the results appeared to present sufficient interest for a preliminary communication. After having for a long time unsuccessfully attempted to obtain borings, he hammered out a piece at a dull red heat to a thin plate, strips of which were taken for analysis. The proportion of the chief constituents was found to be as follows:—

	Per Cent.
Carbon	1·05
Silicon	0·53
Manganese	9·10

The alloy was therefore low manganese steel. Its degree of hardness had already been stated. A chisel made of it readily cut wrought iron and foundry pig iron. Notwithstanding that remarkable hardness, it could be bent in a water-quenched condition. It was not appreciably affected by a one-inch electro-magnet. His special object in that research was the isolation of the so-called carbide. He adopted his original method of treating the steel with dilute sulphuric acid, by which he detected and for the first time examined that substance in the year 1878. In the preliminary experiment, fine borings of the manganese steel and cold acid were employed. In 24 hours' time a dark residue was deposited on the bottom of the beaker. He observed that it differed from the usual carbide in being also insoluble in warm acid. The carbide could in a short time be readily isolated even from compact pieces of metal. He threw about 15 grammes of the plate mentioned into a mixture of 30 cubic centimetres of sulphuric acid and 600 centimetres of water at 60° C. After the evolution of hydrogen had ceased, the solution was decanted, filtered through a weighed filter and thoroughly washed with hot water, and finally with hot alcohol. The filter and its contents were then placed in a small weighing flask closed by a cork, with two perforations containing short glass tubes, one of which was connected with an india-rubber tube for introducing a weak stream of hydrogen or of coal gas. The flask so provided was placed in an air bath and heated for two hours at 120° C. It was then allowed to become thoroughly cool, and to stand for some time without the stream of gas being interrupted. Had

that precaution been neglected, the carbide would have ignited when air entered. Finally, by weighing the flask, the quantity of the carbide was determined. The carbide thus obtained was a dark brown non-magnetic powder which would not scratch glass, and which under the microscope with reflected light resembled a fresh fracture of mild steel. When placed on a glass plate with a drop of water and touched with a small stick of lead, it disintegrated into extremely fine grains about $\frac{1}{1000}$ of a millimetre in diameter. In appearance it differed from the carbide from ordinary carbon steel only in the transparency of the smallest grains. Heated in a stream of dry hydrogen, in a porcelain vessel placed in a strong tube of combustion-glass, the carbide gave off water, and a small proportion of hydrocarbons of an unpleasant odour. After this treatment, the cooled vessel was placed in another tube half filled with granulated copper oxide. The carbide was then burnt by means of dry oxygen. The carbonic acid and some milligrammes of water formed by the oxidation were absorbed and weighed in the usual manner. The oxide remaining in the vessel might be dissolved in hydrochloric acid and analysed. In that manner two analyses of the forged material were made, the first with fine borings in cold acid, and the second with larger pieces in hot acid. In the two cases, the results were practically the same, namely, 1.54 per cent., and 1.56 per cent. Pieces heated to redness and immersed in cold water were then examined, the result being the same, namely, 1.58 per cent. The proportion of carbon calculated from the residue after ignition in hydrogen was 7.5 to 8.0 per cent., of course in accordance with the formula Fe_3C . The following proportions of other elements were present in the residue :—

	Per Cent.
Silicon	1.60
Copper	2.68
Phosphorus	1.20

The proportion in manganese rose from 8.8 per cent. in the forged alloy to 12.1 in the water-quenched. The most noteworthy result obtained was the small proportion of carbide present. Ordinary steel, with 1 per cent. of carbon, would give at least 10 per cent. of that material, whilst even hardened steel

would give more than 4 per cent. Whilst in forged carbon steel, three-quarters of the carbon, and in the hardened steel, one quarter was present in the form of Fe_3C , in manganese steel $\frac{8}{9}$ is really alloyed, not only in the forged, but also in the water-quenched metal. In view of these results, and of those described by Mr. Hadfield, he (Dr. Müller) was induced to study the chemical behaviour of the annealed alloy. A strip was heated for two hours over a gas burner, to a temperature of nearly 1000°C . During that operation, a thin uniform layer of scale was formed, which, curiously enough, was attracted by the magnet like iron scale. The physical properties of the metal did not appear to have been altered, but the chemical composition was somewhat different. The proportion of carbide had increased to 3.67 per cent., and that of manganese to 23.1 per cent., whilst that of carbon was still 7.51 per cent.

Mr. J. W. SPENCER had followed with much interest the very important papers by Mr. Hadfield and Professor Arnold.

With regard to carbon in steel, he did not know that much progress had been made since 1880, when, in the discussion on Professor Akerman's paper at Düsseldorf, he called attention to the fact that his firm's chemist, Mr. T. W. Hogg, at Newburn, in the course of some investigation had noticed and drawn his attention to the existence of a form of carbon in hardened steel neither accounted for in the colour test nor as graphite, and he gave a table of a series of experiments showing that, which was published in the *Journal* (1880, No. II., p. 443). Now that was four years previous to the earliest paper of Professor Ledebur mentioned by Mr. Hadfield. He ventured to suggest at the same time that a carbide of iron might account for the hardening effects, &c., in steel. Carbides of iron had been isolated, but it was still to be *proved* that they existed in that state in the steel, and were not at least partially the products of the reactions used to obtain them. So really still only carbon was known (I.) in its crystalline graphite state as found in pig iron, (II.) in the amorphous form produced by slow annealing of high carbon steels, (III.) as combined carbon as shown in the colour test, (IV.) as that found in hardened steel. All those forms had their individual effect upon the steel containing them, and as

heat treatment was responsible for the particular form in which the carbon existed, it showed the great importance to the practical manufacturer of the study of that matter. Under the varying circumstances of manipulation, analysis was at present only a poor criterion as to the condition of a finished steel casting or forging, and could only be taken as a comparative index of the raw material. If heat treatment could so alter the carbon, and change the nature of the steel accordingly, so also did it affect the molecular condition of the steel itself, for from the same piece of material could be obtained the results of low tenacity and ductility or varying upward to great ductility with corresponding high tenacity, depending upon the treatment. Chernoff had recognised and explained that as regarded forgings, &c., and he had been producing steel castings some time previously with the recognition and appreciation of the same laws, obtaining as a result in the form of ingot or casting only, without any mechanical work being done on the material, equal tenacity and ductility as was only understood to be obtained by the hammer or the rolls; arranging the molecular condition of the steel at the initial stage to give the greatest effect to cohesive attraction, so that no after manipulation could improve it. Considering, therefore, that the physical condition of steel could be so varied and changed by the heat effect upon itself, as well as upon the carbon it might contain, with ever-varying results, he was afraid steel-making was not such a simple art as some would lead one to suppose, nor was analysis of much use in determining the value of the finished article, rather should the ultimate results of mechanical tests be trusted, if it was possible to be sure that the test-pieces were fairly representative of the finished article.

With regard to the very interesting theories concerning recalescence in the cooling and heating of steel he did not venture to give an opinion, but would ask whether there was any necessity to assume several allotropic forms of iron other than the amorphous and crystalline to account for the phenomenon? Could it not be explained by (a) chemical changes in the contained elements themselves, or (b) the molecular change of iron and other elements or compounds from the amorphous to the crystalline state, or *vice versa*? He ventured to suggest this to

Professor Roberts-Austen on hearing his very interesting and instructive lecture at Newcastle, but he did not attach much importance to it.

Since hearing Professor Arnold's paper, it appeared to him that those molecular changes had a great deal to do with it. It was not possible to avoid taking into account the several other elements mixed with the steel—he would not say alloyed—for not only would they affect the points of recalescence by reason of their own individual changes, especially if in any quantity; but also by their reaction in the predominant element itself.

Much more information was required concerning the action and reaction of the various elements in steel on each other under varying temperatures, and considering the powerful effect of phosphorus in minute quantities, it was difficult to say what microscopic amounts of other elements not usually estimated, might have. It would therefore appear that the various changes of the elements and their combinations must have some effect upon the points of recalescence; but it seemed to him that in addition to the carbon changes the molecular change of the iron itself must have the greatest effect, and probably the chief carbon change took place about the same time the steel changed from the crystalline to the amorphous, or *vice versa*.

Mr. JOHN PARRY had read Professor Arnold's research with great interest, and though much was due to him for the mass of original work laid before the Institute, Professor Arnold seemed, however, to have failed to grasp the true scope and object of the able work of Professor Roberts-Austen and Mr. Osmond. It was merely necessary to read the recent masterly summary of these researches to clearly see that they were altogether beyond the limited field to which the author of the paper had apparently confined himself. His experiments were not conclusive nor sufficiently comprehensive. Indeed they hardly touched on the true subject matter of Roberts-Austen's and Osmond's researches, and strictly speaking did not go much beyond ordinary metallurgical practice. The iron used could not be termed a pure metal, and the analysis given was not exhaustive. In addition to the list of foreign elements shown to be present, the absence of others should have been proved. It must be admitted that the

results given have a certain value as bearing on ordinary work where a pure metal was never dealt with. They did not, however, enable any decision to be arrived at as to the correctness of the researches commented upon. The author appeared almost to ignore, upon insufficient data, the application of the periodic law as deduced from the investigations of Professor Roberts-Austen, and condemned much that so able a chemist would on more mature consideration hesitate to do. Mr. Hadfield also appeared to be unfavourably impressed, and disposed to criticise the researches in question. He had not, however, materially damaged the position taken up by his opponents, and like Professor Arnold had apparently not adequately realised what Professor Roberts-Austen and Mr. Osmond really meant. The author (p. 164) seemed to regard the assumption that iron was indeed a polymorphous body as quite inadmissible. In his (Mr. Parry's) opinion nothing was more probable. It had certainly not yet been proved; but in the light of some comparatively recent researches, in which, he might be pardoned for saying, he had borne a small part, there was some evidence pointing to the contrary. If that should prove to be true, it would undoubtedly afford a satisfactory explanation of some remarkable changes known to occur in the physical qualities of iron which chemistry had failed to solve.

Professor ARNOLD, in replying to the voluminous discussion and correspondence on his paper, would, in the first instance, sincerely thank the Council for their kindness in inviting him to lay the results of his investigations before the Iron and Steel Institute. He would also thank the gentlemen who had taken the trouble to criticise the paper, whether from a friendly or hostile standpoint. In framing his answer, he would, as far as was compatible with an unswerving maintenance of his two main positions, bear in mind the commendable words used by Mr. Tomlinson in opening his thoughtful and moderate criticism, namely, that the pure physicist and the applied metallurgist should avoid sneering at each other, and, by an allied attack, endeavour to solve the difficult problem under consideration.

Commencing with the criticism of Mr. Osmond, that gentleman asserted that the author claimed as his own the location of the

crystallising point of iron at AR2, when really the explanation was due to him (Mr. Osmond). Messrs. Osmond and Roberts-Austen also stated that the separation of the point AR2 from AR3 "owes absolutely nothing" to the author. In reply to these assertions, the author would merely quote, without comment, the chronology concerning this matter.

In 1890,* Mr. Osmond considered that the evidence extant justified the view that AR2 must be considered merely the retarded end of AR3. In October 1891,† Professor Roberts-Austen accepted Mr. Osmond's views, and made no mention of the separation of the points ARS 2 and 3, but exhibited recalescence curves of electrolytic iron from which AR2 was absent. In December 1891, Mr. Osmond, in reply to a suggestion of the author's that the combined point was probably due to crystallisation, asserted that the points, ARS 1, 2, and 3 had "nothing whatever to do with crystallisation."

In April 1893,‡ Professor Roberts-Austen, so far from mentioning the fact that the points ARS 2 and 3 had been separated, used, on page 128, words which led to the inference that he regarded its very existence as apocryphal. In the discussion (page 155 *et seq.*), the author, on *thermal* data, pointed out the sharply distinctive properties of AR2, and, on micro-thermal grounds, its connection with the phenomenon of crystallisation. In the correspondence following, Mr. Osmond announced that the result of "an experiment, only briefly indicated in a report as yet subject to revision," had led him, in 1891, to separate the points ARS 2 and 3 on *magnetic* grounds.

In May 1894, Messrs. Osmond and Roberts-Austen stated that the separation of the two points "owes absolutely nothing" to the author; and Mr. Osmond claimed the location of the crystallising point of iron (*if correct*) as his own, on the ground that, in 1888, he made a suggestion that the combined point AR3-2 might be connected with crystallisation. Mr. Osmond claimed the movements or eliminations of the point AR3, observed by the author in response to the addition of certain elements to iron, as proof of his theory, in spite of the fact that the author had also shown that the point AR3 was absolutely uncorrelated with the mechanical properties

* *Journal of the Iron and Steel Institute*, No. I. p. 47.

† *Proceedings of the Institution of Mechanical Engineers*, p. 543 *et seq.*

‡ *Ibid.*

of the alloys. To meet this, Mr. Osmond asserted that, in employing an average amount of 1·5 per cent. of the added element, the author had exceeded the limits of the law, more particularly mentioning the case of phosphorus, and had hence sought a confirmation where it was impossible. The author's reply to that remarkable defence was simple—namely, that the research upon which Mr. Osmond definitely announced, as applicable to the iron and steel industry, the working of the combined laws was made upon a series of otherwise exceedingly impure alloys, ranging in the proportions of the added elements from 0·3 to 6 per cent., and moreover, Mr. Osmond claimed the properties of Hadfield's alloy, containing 15 per cent. of manganese, as experimental proof of the accuracy of his theory, and the percentage of phosphorus in Mr. Osmond's alloy was identical with that present in the author's. Messrs. Osmond and Roberts-Austen had both asserted, without qualification, that the author formerly attributed the point AR3 to hydrogen. Upon the ethics underlying such a statement the author would make no remark, but would merely quote his actual words. "I would suggest, as a tentative hypothesis for inquiry, the possible influence of the element hydrogen." * As a matter of fact, the exact relations of iron and hydrogen were still unknown.

With reference to the alleged allotropic change occurring at the point AR2, Mr. Osmond suggested that the author's position in that matter was due to the ignorance of the definitions of elementary chemistry prevalent in Sheffield. Such, however, was not the case. The simple explanation was that the author considered the change occurring at AR2 to be more akin to congelation than to allotropy.

With reference to electrolytic iron, the author fully admitted the importance of Professor Roberts-Austen's recent experiments, and also that his (the author's) position, that the point obtained in his impure electrolytic metal was entirely due to the sulphur and carbon present, was untenable. At the same time, the new observations also proved the pertinence of the author's criticism as to the abnormal or inaccurate nature of the curve exhibited at the reading of the first report of the Alloys Research Committee, inasmuch as Professor Roberts-Austen now admitted incidentally that the point AR2 was present in electrolytic iron, though he had

* *Proceedings of the Institution of Mechanical Engineers*, 1893, p. 158.

not stated if he still maintained, in opposition to the observations of Mr. Osmond and the author, the view that it was a truly reversible point. With reference to the remarkable observations published by the author, that the heat evolved even in impure electro-iron at AR3 was only about one-fourth that permanently registered after certain thermal treatment in steel containing 0.16 per cent. of carbon, Mr. Osmond was silent, and Professor Roberts-Austen merely asserted that the fact was in favour of the theories attacked, but he unfortunately failed to explain why such was the case, nor did he state why the carbon change point at AR1 had practically disappeared. The fact last named proved the inaccuracy of Professor Roberts-Austen's contention that Mr. Osmond had proved the sum of the heat evolved at AR2-3 was constant and independent of the carbon present. Professor Roberts-Austen's assertion, that because the point AR3 was present in electrolytic iron, therefore most of the author's conclusions fell to the ground, was, to say the least, forensic. As a matter of fact, the author's final conclusions did not involve the point AR3, inasmuch as before framing them he specifically recognised the possibility of its appearance in pure iron.

It was evident that the author's opponents did not care to discuss the main subjects of the paper, but preferred to wander away into a discussion on the abstract allotropy of iron. The author's paper had reference to an alleged *specific* allotropic modification of iron of *adamantine hardness*, formed above 900° C., and rendered stable or unstable at the ordinary temperature by the action of *specified elements in accordance with their atomic volumes*. Moreover, the dual hypothesis was placed before the iron and steel world as of the *utmost practical importance*; indeed, eight years ago, Professor Roberts-Austen, in discussing a paper by the author on Bessemer steel tires, definitely asserted that the action of elements upon such material should be in accordance with the periodic law.

In discussing the allotropy of iron, Professor Roberts-Austen considered that the position of Mr. Osmond and himself was much strengthened by the fact that the element sulphur was known to possess hard and soft modifications. Strings of the plastic form of sulphur were exhibited to members of the Institute. Professor Roberts-Austen considered the allotropy of

sulphur to form an admirable analogue for the allotropy of iron : the author would therefore call the attention of the Institute to certain facts which seemed to him to considerably weaken this line of argument. Firstly, sulphur was a *non-metal*, melting at 115° C., whilst iron is a *metal* melting about 1700° C. ; secondly, the soft modification of sulphur was produced by sudden cooling, that of iron by slow cooling ; thirdly, both modifications of sulphur could be readily prepared and their properties examined at the ordinary temperature : only the soft modification of iron was known, the alleged hard variety being hypothetical ; fourthly, the allotropic forms of sulphur were assumed by the pure substance, whereas it was supposed to be necessary to maintain the iron in the hard condition, to have present amongst the groups of Beta molecules those of some other element of atomic volume less than that of iron. On the whole, therefore, the sulphur argument, however plausible at first sight, was not adapted to carry conviction of the accuracy of Professor Roberts-Austen's theories to the minds of chemists and physicists.

Professor Roberts-Austen had complained that the author had not quoted the remarks of a number of pure physicists. This omission was not due to any lack of respect for such work, but to the fact that pure physical researches were not of immediate interest to an Institute specially devoted to the advancement of applied science. Professor Roberts-Austen had also expressed his regret that the author did not set forth the history of the conversion, which led him to recognise the value of the method of thermal observation inaugurated by Mr. Osmond. Professor Roberts-Austen asked for the history of an event which never happened. In the first public attack the author made on the *β iron theory*, he also stated that the practical portion of Mr. Osmond's work was of such importance and value that all future researches on steel would be incomplete, unless observations by Mr. Osmond's method were correlated with the chemical, mechanical, and microscopical tests.* Also in the correspondence on Mr. Hadfield's paper on the alloys of iron and chromium read before the Institute, the author bore the strongest testimony as to the value of Mr. Osmond's and Professor Roberts-Austen's work.† The author was therefore quite unable to comprehend

* *Proceedings of the Mechanical Engineers*, 1891, p. 587.

† *Journal of the Iron and Steel Institute*, No. II. 1892, p. 168.

the meaning of Professor Roberts-Austen's unjustifiable remark. There was, however, one point with reference to Mr. Osmond to which the author would like to refer. Experience had shown him that some metaphors used in 1891 to exemplify the exaggerated nature of Mr. Osmond's curves were also exaggerated, and he therefore withdrew the expressions then uttered, and wished to express to Mr. Osmond his sincere regret for having employed them.

The contribution of Mr. Gowland to the discussion would be welcomed by all opponents of the β iron and periodic law theories. The argument of that gentleman ran thus—

Because the addition of 0.1 per cent. of bismuth to malleable copper containing 0.35 per cent. of arsenic prevented it forging, it was therefore impossible to determine the true mechanical influence of elements on iron, when the latter contained 0.1 per cent. of carbon.

What stronger evidence could be adduced to prove the author's contention as to the utter industrial uselessness of the periodic law theory when applied to the metallurgy of iron? The author's alloys were far purer than any capable of being prepared in ordinary industrial operations, and yet Mr. Gowland stated that they were too impure for the law to act. Mr. Gowland, however, had proved a little too much, having overlooked the fact that the carbon present in the alloys of Group I. would distinctly act in the direction of proving the theory, and yet in spite of the influence of the carbon, the quenched bars bent double. Surely Mr. Gowland did not mean to assert that in the absence of the 0.1 per cent. of carbon the nickel bar would have broken short, yet it was difficult to draw any other practical inference from his remarks.

The contribution of Mr. Tomlinson as a pure physicist was of considerable importance. He was inclined to admit the general accuracy of the author's conclusions with reference to "mass" hardness; but stated that microscopic granules of hard β iron might be present in an apparently soft metal. No possible exception could be taken to such an enunciation, which was in accordance with the abundantly-demonstrated fact that *invisible molecular* changes were in the best defined cases of the allotropy of solid bodies accompanied by *visible structural* alterations.

Why then did not β iron theorists demonstrate that in an alloy of nearly pure iron and nickel, such as that employed by the author, there existed microscopic areas of adamantine hardness? The answer to that question was easy. No such areas were present. By the author's method of preparation patches of hard β iron could be detected with certainty, even if only $\frac{1}{80,000}$ of an inch in diameter.

Mr. Tomlinson, however, confirmed Professor Roberts-Austen's remark that the author's statement with reference to the coincidence of the point AR2 with magnetism was "most inaccurate." Again the author would reply by a reference to history. In the *Proceedings of the Mechanical Engineers*, April 1893, page 196, would be found, in a letter from Mr. Osmond to Professor Roberts-Austen, the following words:—"By subsequent direct experiments, however, which have been confirmed by yourself and Mr. Herbert Tomlinson, it was found that in cooling curves the appearance of magnetism in iron coincides exactly with the intermediate point AR2."

The author accepted as correct the above statement, but Professor Roberts-Austen now stated that the experiments then made by Mr. Osmond, himself, and Mr. Tomlinson, were most inaccurate. That the author learned with regret, as he had always had a faith in the experimental ability of all three gentlemen, only equalled by his conviction of the inaccuracy of the theories they deduced from their experimental results.

However, the author still held that the point AR2 was most intimately associated with magnetism, that remaining above AR2 on heating being a small residuum, and the permeability between AR3 and AR2 on cooling was very slight. An experiment made by the author on his nearly pure iron indicated the disappearance of magnetism to practically coincide with the point AR2, and consequently with the disappearance of crystalline structure.

Mr. H. C. Jenkins referred approvingly to the author's preparation of "a series of test bars" (he appeared to have overlooked the fact that the paper also contained some correlative references to recalcence and microscopy), but suggested that possibly the author neglected the elementary precaution of obtaining strictly comparative results with reference to the rate of loading. Such,

however, was not the case. Mr. Jenkins also gave the author instructions how to obtain discordant mechanical tests from bars of pitch. The author's paper was on alloys of iron, a subject to which he had devoted fifteen years of close study. His experience with pitch, for proverbial reasons, was limited. The author would suggest to Mr. Jenkins that if he would devote some time to a study of the microscopical structure of iron and steel, he would then be in a position to supplement his interesting but purely hypothetical molecular theory with the statement as to which of the three distinct microscopical constituents always present it referred.

Mr. Jenkins, referring to the author's experiment with boron, had lost sight of the fact that it was a result obtained in a comparative series of experiments on the alloying of elements with iron. Professor Roberts-Austen had defended the unanalysed 4-gramme button upon which the molecular action of boron was decided. Mr. Osmond, however, admitted that the matter required further consideration. It might interest Mr. Jenkins to know that previous to the reading of his paper the author also had commenced a research on boron steel. It would therefore be interesting, when the two sets of experiments were published, to compare the results obtained on laboratory buttons and bars from industrial ingots. For the present the author would merely state that recalcence curves obtained from a piece of veritable boron steel, previously submitted to exhaustive analysis, indicated that the molecular action of boron was very different from that of carbon.

Mr. Jenkins did not admit the accuracy of the author's conclusions from his experiments on the crystallising point of iron. He considered the crystallisation point stated by Mr. Osmond to exist above 900° C., to be identical with that observed by tool-smiths "at 800° to 1000° C." This point Mr. Jenkins considered to agree "more nearly" with the point noted by Dr. Ball. In the author's opinion, determinations of crystallising points made by tool-smiths must be regarded with some degree of doubt, and the author would also suggest, that as Dr. Ball's point was noted about 1250° C., it could hardly be considered to approximate a point ranging from 800° to 1000° C.

It is evident from Mr. Jenkin's criticism that he had not carefully followed the correlation of the author's micro-thermal

results with the recalescence curves given by the iron on heating and cooling.

Mr. André Le Chatelier, although not agreeing with Messrs. Osmond and Roberts-Austen that the hardness of quenched tool steel was due to β iron, nevertheless thought that the properties of Mr. Hadfield's alloy were due to β iron. The author thought that Mr. Le Chatelier could not be aware of the vital micro-chemical results obtained by Mr. Stead. The author admitted the accuracy of Mr. Le Chatelier's view that the remarkable result he obtained on an iron wire in raising the strain from 21 to 60 tons could not be entirely due to the 0.06 per cent. of carbon present. But it was not clear that such a result might not be brought about by the combined influence of the carbon and the abnormal state of crystallisation brought about by the sudden chilling of the small specimen. The phenomenon appeared to be identical with the great increase in tensile strength observed on comparatively mild steels when drawn into wire in which, *especially in steels abnormally high in silicon* (which should theoretically lower the stress), stresses of 150 tons per square inch were obtained.

The contribution of Professor H. Le Chatelier deserved the closest attention of steel metallurgists, and the author noted with great satisfaction his declaration with reference to the hardening of steel. He also called attention to the great influence of structure, independently of molecular condition, on the mechanical properties, and for this reason did not think that a careful observation of tenacity and ductility at high temperatures will be of much use in determining the existence or non-existence of allotropic modifications of iron. The author, however, thought that valuable information was thus to be gained, and was now preparing a series of determinations—containing the excellent work of Professor Le Chatelier himself at lower temperatures—the object of which was to obtain a curve of the ductility and tenacity of nearly pure iron on points set out every 50° between 600° and 1000° C. The author was of opinion that above 750° the crystalline structure ceased to exist, and that therefore such curves should give important evidence for or against the allotropy of iron at 850°.

The author admits the possibility of Professor Le Chatelier's
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suggestion that the point noted on heating alloys of sulphur and iron might be a fusion point, but on the other hand the regularity of the position of the two new points observed on cooling would rather point to the formation of definite compounds.

In replying to the courteous and able criticism of Mr. H. Louis, the author would point out that that gentleman did not seem to have seen the various stages of the β iron controversy. The author had never, as Mr. Louis thought, denied that iron was capable of assuming an allotropic state. The author's attack was on the alleged existence of an allotropic modification of *intense hardness* to which, and not to a carbon compound, the hardness of quenched tool steel was stated to be due, and which was capable of being rendered stable at ordinary temperatures by nickel, &c.

With reference to the observations of electrolytic iron by Professor Roberts-Austen and the author, Mr. Louis was a little confused as to the sequence of events. Professor Roberts-Austen's first experiment (made owing to the fact that very properly he was not satisfied with Mr. Osmond's observation on electrolytic iron containing 0.08 per cent. of carbon), the curve of which was published in the *Proceedings of the Institution of Mechanical Engineers*, October 1891, showed that the point AR2 was absent, thus apparently confirming the view of Mr. Osmond that it was the end of AR3 for the iron immediately dependent on the carbon atoms. The curve also showed that the point AR3 was exactly reversible. No statement was given showing the amount of sulphur present in this specimen. Hence the author's experiments. Professor Roberts-Austen's subsequent observations were not announced till the meeting at which the author's paper was read. The author trusted that Professor Roberts-Austen would shortly publish the exact curves obtained, as it was evident that the true curve given by electrolytic iron free from carbon and sulphur had not yet been publicly recorded.

With reference to Mr. Louis' remarks concerning the carbide of iron, so far from ignoring the influence of the carbon, the author repeatedly referred to it, and in the micro-sections figured, called attention to its exact distribution and location. The author regretted that Mr. Louis should mar an otherwise fair, though hostile, criticism with so unjust a reflection. Moreover, since

Mr. Louis was inclined to split hairs on this matter, the author would remark that, excluding the cases of the manganese and chromium alloys, which the author especially separated on account of the impurities present, the average carbon was not 0.10, but 0.07 per cent. The author had read with interest Mr. Thwaite's suggestion that the points of recalescence could be explained on thermo-dynamic grounds, but it appeared to him that such an explanation involved recalescence points in all metals—*e.g.*, gold and copper—which, as far as the author's knowledge went (and he had before him a beautiful autographic curve of the cooling of gold, taken by Professor Roberts-Austen by means of his autographic recorder), did not exhibit such points.

In discussing the criticism of Mr. Harbord, the author wished in the first instance to express his regret to Messrs. Harbord and Tucker, that, by an oversight, a reference to their exceedingly valuable experiments on the influence of arsenic on mild steel was not included in the paper.

Mr. Harbord had evidently imperfectly grasped the objects of the author's paper. The differences in the percentages of the added elements, the author admitted, would have been better absent, but they in no way interfered with a comparison of the alloys with the standard iron, or of the determination of the influences of the elements with reference to their positions in Mr. Osmond's groups. The substitution of a nickel alloy containing 1.8 instead of 1.5 per cent. would not have appreciably altered the tensile results.

With reference to Mr. Harbord's remarks about arsenic, the author would call attention to the fact that his alloy only contained 0.16 per cent. of total impurity. Mr. Harbord's samples were much more impure, and therefore could not be quoted as evidence of the influence of arsenic on nearly pure iron, which was the immediate subject under consideration.

As Mr. Stead had pointed out, Mr. Harbord obtained from a mild steel containing 0.6 per cent. of arsenic a reduction of area of 54 per cent. Did Mr. Harbord wish it to be understood that 0.3 per cent. of phosphorus would have given a similar result?

Mr. Harbord's remarks on the author's bending tests showed clearly that he did not appreciate the author's objects, although it was expressly stated that the bars were purposely kept small in

order that they might be quenched with the greatest possible rapidity. If the chromium bar answered to the 0.17 per cent. of carbon present, the nickel bar would have indicated readily the β iron produced by 1.5 per cent. of nickel had the iron assumed even partially a hard allotropic modification. With reference to Mr. Harbord's remark concerning the determination of the hardness of the alloys by Mr. Turner's apparatus, the author might explain that a series of tests for abrasion hardness showed so little difference between the different alloys that it was not thought worth while proceeding with them, only the phosphorus alloy exhibiting any palpable hardness. The samples, however, could still be submitted to Mr. Turner, but as Mr. Harbord had proved to his own satisfaction that the whole of the author's research was useless, it seemed hardly necessary to go further with the matter on his account. Mr. Harbord quoted an alleged atomic volume classification by Professor Roberts-Austen as a proof of the accuracy of the periodic law theory. He also for comparison included results "deduced" from the author's experiments. The nature of Mr. Harbord's deductions might be exemplified by the facts that he classed the tensile test of the nickel alloy, which gave a maximum stress of 26.8 tons per square inch as a "distinct increase," whereas he classified the tungsten alloy, which stood a stress of 27.24 tons, as a "slight increase," both being compared with the iron which stood 21.77 tons. He also stated that the tungsten and chromium alloys gave little or no reduction in area or elongation. The first named was respectively 76.6 per cent. and 72.1 per cent., the latter being respectively 42.5 per cent. and 40 per cent. However, in spite of hostile intent, Mr. Harbord had done the author good service by furnishing him with a graphic comparison of the utterly incompatible arguments by means of which supporters of the periodic law theory as applied to iron and steel endeavoured to maintain their position. Mr. Gowland justified the theory on the ground that the author's alloys contained 0.1 per cent. carbon, and were therefore useless for any attempt to experimentally verify or disprove the law.

Mr. Harbord defended the law on a classification including Schneider armour-plates and Hadfield's manganese steel, which Mr. Harbord declared was "Professor Roberts-Austen's own enunciation of the law." Mr. Gowland and Mr. Osmond, on the

other hand, protested that the law was limited, and only applicable to "traces" of the added element introduced into chemically pure metals. The whole Mr. Louis termed a "workable hypothesis." The remarks of Mr. Spencer with reference to the existence of carbides of iron were now likely to be fully appreciated. The author would shortly have pleasure in sending to that gentleman the results of a research which proved beyond doubt that the carbon present in an annealed steel could be microscopically examined *in situ* before isolation, and also after isolation, in the identical form in which it existed in the iron. The carbide thus obtained contained practically the whole of the carbon present in the weight of steel taken for analysis. Its composition corresponded exactly to the formula Fe_3C , and in physical appearance it consisted of small, hard, silvery plates showing not the slightest appearance of having undergone chemical decomposition during their separation from the mass of the iron.

The criticism of Mr. John Parry was general rather than specific, and dealt more with matters of opinion than of fact. That was unfortunate, because, as Mr. Stead very truly remarked, what was required in the question at issue was "solid fact." As the author had already pointed out, his object was not to deal with the abstract principles governing the allotropy (if any) of metals, but to strenuously oppose an ill-considered attempt to apply undemonstrated theories in a specific manner to the practical metallurgy of steel. Mr. Parry objected to the impurities in the author's alloys, oblivious of the fact that they were the purest series extant, and that, if the theories attacked would not apply to them, they could not possibly influence to any measurable extent the far less pure metals made in ordinary practice.

Mr. Parry appeared to urge that if perfectly pure iron bars, containing only single elements, were investigated, the action of the periodic law theory would then become apparent. That position had the advantage of defying practical refutation, because the preparation of such a series of bars seemed at present to be an impossibility. On the other hand, however, Mr. Parry could not pretend to offer any experimental proof in support of the position he had taken up. Mr. Parry's contention, if it meant anything practical, meant that small bars of chemi-

cally pure iron containing 1 per cent. of nickel, and quenched from a white heat, would be hard, whilst under similar conditions iron containing 1 per cent. of phosphorus would be soft, but that, owing to the $\frac{2}{10}$ per cent. of total impurity in the author's alloys, the above properties had become reversed. The accuracy of such views the author emphatically disputed.

Mr. Parry called attention to the well-known fact that chemical analysis failed to explain the mechanical properties of certain steel, and he therefore fell back upon Professor Roberts-Austen's and Mr. Osmond's theories for an explanation, most unfairly ignoring the remarkable differences in crystalline structure laboriously determined and figured in the author's paper. The fallacy of such an argument would be evident after reading the well-weighed words of Professor Le Chatelier. Mr. Parry considered Mr. Hadfield and the author were unable to grasp the true scope of Mr. Osmond's and Professor Roberts-Austen's theories. If this be so, they must plead as an extenuating circumstance for their lack of intelligence, the fact abundantly demonstrated during the discussion on the paper, that the disciples of those gentlemen also seemed to be in a similar predicament. The only really practical point raised by Mr. Parry was an expression of opinion that the iron used should have been analysed for elements other than those tabulated. As a matter of fact the material gave negative results when qualitatively examined for arsenic, copper, nickel, chromium, titanium, and tungsten. Hydrogen was of course present. Why did not Mr. Parry state to what other elements he referred, and forecast their effect on the results? In the absence of such definite grounds of objection, his criticism did not tend to serve any useful purpose.

In conclusion, the author would point out the overwhelming preponderance of opinion amongst the distinguished metallurgists who have taken part in the discussion, that the hardness of quenched high carbon steel was not due to β iron.

With reference to the law of atomic volumes, it now seemed, from the remarks made by most of its supporters, that its position with regard to practical steel metallurgy may be fairly stated as follows:—

That, under certain circumstances unattainable in industrial

operations, within certain limits (not yet determined), the law might be generally depended upon to act.

It was therefore evident that the theory should have been cultivated in academic shades, and not have been put forward to wither in the glare of applied science. The author ventured to claim that the results of the discussion had fully proved the accuracy of the final conclusions drawn from the results of his research, and summarised under two heads on the last page of his paper.

The author had only one cause for regret in the criticisms on his work, viz., the small attention attracted by the microscopical section. Upon the great importance of this method of investigation in research he could not too strongly insist, and hoped shortly to publish the accumulated observations of five years, which would also show its great practical utility in accounting for the failure of steel which the results of ordinary chemical analysis had failed to explain.

Mr. R. A. HADFIELD (Member of Council) said that he had so fully dealt with several of the points brought forward by Professor Arnold in his (Mr. Hadfield's) own paper, and for the appearance of which at this time he had to thank their President, that he had but little further to add in regard to his views on this important subject. He believed that Professor Arnold's paper would be a standard of reference on these matters for some time to come. It seemed to prove that the hypothesis as to the existence of a β or hard form of iron could not be accepted. He fully admitted that if the existence of such a form could be proved, it would be a most convenient and ready way of explaining any difficulties experienced. But if the various facts that had of late been brought to light by various workers showed this to be untenable, it seemed to him that true progress, on right lines, would be seriously hampered if they continued to entertain theories so at variance. The paper was so complex that it was not easy to discuss it fully in the manner it deserved without more time for consideration.

Although he had had the pleasure of seeing results at the Technical School at Sheffield from time to time, the paper itself had only been in his hands four days. Nevertheless he entirely

agreed with the conclusions drawn, that seeing the results obtained, one could not accept the β iron hypothesis. The numerous experiments he had carried out with alloys confirmed the conclusions arrived at respecting the latter point, and especially that relating to manganese alloys. These, Mr. Hadfield said, were dealt with very fully in his own paper; but he might, perhaps, briefly refer to one or two of the leading points. Manganese steel was non-magnetic. That was an alloy containing about 12 per cent. of manganese, 1 per cent. carbon, and 87 per cent. of iron. Many explanations had been offered as to why this material possessed this peculiar non-magnetic character. One was that as it was hard, and at the same time non-magnetic, there was clear evidence of the β iron, which was also claimed to be non-magnetic. However, by continuous heating and very slow cooling, this material had been made to become magnetic; but what was still more curious, the same material could be again made to become non-magnetic, by merely forging and heating to about 1000° C. and quenching in water; the latter part of the treatment not being absolutely necessary, though it intensified the effect. Thus, by treating a bar as above named, then retreating a portion of it, it was possible to have on the same piece of material a magnetic and non-magnetic condition. He fully believed that it was entirely owing to the formation of a particular and powerful carbide of manganese that the very peculiar properties of manganese steel were due. He thought his friend Mr. Stead would have something to say on this point too. It was also very fully confirmed by some remarkable results obtained by Dr. Hopkinson several years ago, and which would be found detailed in his paper. It would be possible to discuss this most fascinating subject for a period which those not so specially interested might resent. But he believed that a correct understanding of the points involved would throw much light upon many metallurgical problems hitherto difficult and anomalous.

Respecting the sample of nickel steel exhibited by Professor Roberts-Austen, which showed the curious property of becoming magnetic by submission to a temperature of 50° C., the behaviour was certainly remarkable; but from the results of his (Mr. Hadfield's) own experiments, he had always found that nickel-iron

alloys were much less stable in their non-magnetic properties than manganese steel, probably from the very reason that such alloys were usually much lower in their contents of carbon. This could be easily understood, as practically pure nickel was readily obtainable, whereas pure manganese was a rarity, and to get sufficient to make a 25-lb. or 50-lb. ingot of carbonless, or nearly so, manganese steel was not easily accomplished. In fact, it had only lately come within the region of possibility, owing to the excellent work of Mr. W. H. Wahl in the production of special alloys.

A still more important point was the question, In what way did the nickel steel, which by freezing had become non-magnetic, prove that there was a β or hard form of iron, as both the magnetic and non-magnetic portions of the bar were of practically the same hardness and could be easily filed? If the non-magnetic portion had become hard, like hardened carbon steel, or even manganese steel, then it would be quite another thing. In making these remarks, he would wish that Professor Roberts-Austen should clearly understand that he had no objections to molecular changes being termed allotropic if any good purpose could be served, but to him it seemed that these changes might be found due to changes of crystallisation rather than to a change in the forms of the elements. However, the exact nature of such changes was rather to be determined by the physicist. As one who dealt with the matter more from a practical point of view, and as a manufacturer, he certainly would not attempt to define the nature of such changes. He did, however, strongly contend that, as regards the existence of an allotropic hard form of iron, that is, a β hard form, he considered the case was not proven, and this he must hold until the contrary could be shown by facts. The sample in question being exceedingly soft when tested by an ordinary file, both as regards the magnetic and non-magnetic portions, in what way could it be claimed that they resembled those obtained with carbon tool steel where soft iron, whether α or otherwise, has been turned into the intense, almost diamond, hardness of hardened steel? No stronger evidence could have been adduced than were the excellent specimens of this separated carbide which had been produced by Mr. Stead. In these the hardening element was isolated and clearly brought to light. The exact nature of the effect of this carbide upon the

magnetic properties of iron might not yet be fully clear, but to have separated in such an unmistakable manner material which gave the hardness of manganese steel, either in the magnetic or in the non-magnetic state, was a most important link in the chain of evidence. It seemed to him that nothing stronger could be adduced, and he was glad to find that view confirmed by so eminent an authority on the matter as Mr. Stead. In conclusion, Mr. Hadfield would heartily re-echo the wish of Professor Roberts-Austen that this controversy should be conducted on both sides with an entire absence of personal feeling. Each side willingly conceded to the other that the advance of metallurgy was the aim. A very valuable and, it was to be hoped, international discussion would probably occur on this matter, and much light be thrown on many different questions, the solution of which should ultimately benefit the manufacturer.

Replying to the written discussion on his paper, Mr. Hadfield said that some of those contributing to the discussion questioned the influence of the carbide upon magnetic properties of iron alloys. Seeing, however, the remarkable evidence adduced by Mr. Stead, also the remarks of Professor Ledebur, Dr. Wedding, and Dr. Müller, it seemed to him that, without doubt, its existence and power had been clearly proved. He also thought that Mr. Gilchrist's excellent suggestions ought to be seriously considered, and a Research Committee on this important matter appointed by the Institute.

Dr. Hopkinson referred to non-magnetic samples of 25 per cent. nickel steel. Mr. Hadfield had made a considerable number of special alloys of nickel steel, including that particular percentage, but had not been able to obtain any with non-magnetic properties. These alloys were all very low in carbon, say 0.15 per cent. or under. Possibly the samples referred to by Dr. Hopkinson contained more carbon. If so, these would go to prove the importance of the carbon present, probably in the form of a carbide, to influence the magnetic properties of iron.

Mr. Hadfield did not say these results were entirely influenced by the carbide present, but markedly so. The behaviour, too, of the magnetic specimens of nickel steel wire, in which the tensile strength increased from 50 to 80 tons, would seem to indicate

some change of carbon, and thus indirectly confirm its influence upon magnetic qualities. The remarks by Mr. A. Le Chatelier, respecting the desirability of observing the variations in volume of the various alloys, he hoped would receive attention.

In conclusion, he would observe that this whole question was a very complex one, but the excellent discussion evoked by his paper was, he thought, sufficient justification that the matter was now becoming an important one, and would soon take practical form.

VOTES OF THANKS.

The PRESIDENT asked to be permitted, before they separated, to submit the following resolution:—"That the thanks of the Iron and Steel Institute be and are hereby tendered to the President, Council, and Secretary of the Institution of Civil Engineers for the use of their rooms, and for the facilities otherwise afforded for the present meeting." He was sure it would meet with the approval of the members if he added:—"That the members, desiring to express their sense of the great kindness extended to them over a lengthened period by Mr. Forrass, request him to accept a piece of plate as a permanent testimonial of their regard. They regret the state of his health prevents his being present to receive it, and sincerely hope that his health may be speedily restored."

Mr. JAMES RILEY, Vice-President, seconded the motion, which was carried with acclamation.

Mr. STEAD said he had great pleasure in proposing—"That the cordial thanks of the Iron and Steel Institute be and are hereby tendered to the President for his admirable conduct in the chair."

Mr. ERNSHAW HOWELL seconded the motion, which was unanimously agreed to.

The PRESIDENT said he formally but sincerely thanked the members for their acknowledgment of his services.

ELECTRICITY AS A MOTIVE POWER IN THE IRON AND STEEL INDUSTRIES.

By D. SELBY-BIGGE.

IN accepting the invitation of the Council of this Institute to write a paper on Electric Power applications, the author can only hope that, however unworthy his paper may be in itself, it may yet be the means of bringing forward a comparatively new subject in which considerable interest is being evinced by engineers at the present time, and that, in this manner, the opinions of more experienced men will be brought forth, and additional light thrown on the subject.

During the past three years the author has been almost exclusively engaged in applying electricity in the form of power to different mining and industrial operations, and in the course of his work, has been struck with the vast field which lies open to the application of electric power, and the numerous branches of engineering to which the new, and, perhaps, it may be said, coming power, is applicable.

In taking for the subject of his paper Electricity as a Motive Power in the Iron and Steel Industries, he will endeavour to trace out those branches of the iron and steel industries in which electricity in the near future may take a predominant part. It will be his endeavour in the following pages to treat the subject as far as possible from the standpoint of those engineers who are connected with the daily management of iron and steel works, &c., and not from that of a purely electrical engineer.

Electric power has been applied in this country hitherto chiefly for the purposes of traction, or for carrying out various operations in mining work, such as hauling, pumping, winding, ventilation, drilling, &c., and its chief advantages and characteristics in these branches are now very generally known. All these applications, up to the present, have come under the head of long distance transmission, and there has been a general tendency on the part

of engineers to consider applying electric power only in those cases where the power has had to be transmitted a considerable distance. The author is particularly anxious to draw the attention of engineers to what he may term short distance transmission, or concentration of power. Seeing that it may be considered as coming within the scope of the iron and steel industries, ironstone mines, blast-furnaces, iron and steel works, engineering shops, shipbuilding yards, he will endeavour to point out the cases in which electric power is applicable to each of the above.

1. LONG DISTANCE TRANSMISSION.

Ironstone Mines.—When transmitting electric power over long distances it is necessary, in order to keep down the cost of the conducting cables, to employ high-tension currents, that is to say, the generating dynamos are wound to give off their power at a high voltage and small current. It has hitherto been the practice in mining work to convey the power at voltages of 300, 500, or 800 volts. Electric power in this way may be transmitted with a comparatively trifling loss to distances of several miles in length. It was not long therefore before electricity found an opening in its application to various mining operations, and especially to hauling and pumping. It was the author's privilege some two years ago to apply electricity in the Cleveland mines for drilling purposes, and since then these electric drills have proved themselves in every way a thorough success, and their use is being further extended into other mines in the district. The voltage in the case of the electric rock-drills does not exceed 300, as the power involved is comparatively small, and the distances do not exceed one to two miles in length.

In the case of ironstone mines situated at any great distance from the main line, or in cases where a special line has to be built to the mines, an electric plant could be laid down, not only to operate the drilling in the mine, pumping the water, hauling out the ironstone, but could also be employed to generate current, at the same time for performing all the traction on the branch line. The whole of this work could be performed by current generated from a single engine and dynamo at the mine itself.

In the case where several ironstone mines are situated in close proximity one to the other, a central power station could be laid down, by means of which there would be no separate steam plants situated at the different mines, these all being replaced by electric motors, driven off one main generating dynamo situated at the central station. There is no difficulty whatsoever in carrying out the winding, hauling, pumping, drilling, and ventilating arrangements at these mines electrically.

Blast-Furnaces.—There may be some at this meeting who may think that the author now proposes to work blast-furnaces by electricity. He regrets, however, it is not yet in his power to revolutionise the world by doing this. He would, however, seek the aid of blast-furnaces in generating his electricity, and considers that, after a waterfall, a Cleveland furnace is the next best friend to those desirous of generating electric power economically. In many cases there are large amounts of waste gases available from the furnaces. These are generally used for firing the boilers necessary for driving the blowing-engines, &c., but there is frequently a considerable amount of waste gas left over. It is with this waste gas he would propose firing the boilers in connection with the electric generating plant. The power thus generated could be transmitted at a high tension to engineering works situated at a considerable distance and, if necessary, transformed again to a lower tension for use in the works.

At blast-furnaces themselves there are not a great number of applications to which electricity could be adapted for driving purposes, excepting perhaps in pumping water from a neighbouring river for condensing. The mineral hoists could be worked electrically.

From the few remarks above, engineers will easily be able to see for themselves the cases in which electric power is applicable at the mines and in connection with blast-furnaces.

2. SHORT DISTANCE TRANSMISSION AND CONCENTRATION OF POWER.

Iron and Steel Works.—By short distance transmission the author means the distribution of electrical energy for the purposes of driving engineering works. As already mentioned, there has

hitherto been a tendency on the part of engineers to consider electricity as applicable only in those cases where the power has had to be transmitted over a long distance. It is now necessary to consider quite a different case, in which the power has only to be transmitted over distances not exceeding 300 or 400 yards in length, but in which area a multiplicity of uses may be found for the application of electric power to driving various classes of machinery.

First of all, let the case of iron and steel works be taken, and the classes of machines most frequently employed in these works be considered. These will be found in a great measure to consist of the following: Punching and shearing machines, straightening machines, cold and hot saws, drilling machines, planing machines, blowers, overhead travellers, locomotive cranes, rolls, winches, scrap breakers, &c. &c.

In connection with iron and steel works there are frequently found girder shops, fitting shops, &c., in which the machinery is driven through shafting and belting off one or more engines situated in the shop. In laying down machinery of the above class it has almost invariably been the practice, not only when the machine tools are driven by separate engines, but also when they are driven by belting and shafting, to make allowances in these engines for very large losses, due to condensation or leakage in steam pipes, or to friction caused in the belting and shafting. It is a well-known fact that the power actually expended in performing the work on these various machines is a mere fractional part of that transmitted from the generating source. In those cases where the machine tools have been driven by separate engines, it has been a regular practice to provide engines with cylinders sufficiently large to compensate for any possible losses which may occur through leakage, condensation, &c. It seems generally to have been the practice in engineering works to indicate the main driving engines, but during the author's visits to some thirty or forty of the principal engineering works in this country, he has never been able to obtain indicator diagrams showing the power absorbed by each steam-driven machine tool in the works. Although attention has been paid to the economy of the main engines, the question of that in the small engines driving these machine tools,

and the conveyance of steam, has often been entirely overlooked, and an enormous waste has been going on in this manner for years past.

With the advent of the electric motor this condition of things was at once changed. Every electric motor may be said to be a self-indicating machine in itself, in that the power which it absorbs can be immediately detected through the readings on the ammeter and voltmeter provided in connection with the motor.

The following are results of experiments that have been recently carried out by the author, in conjunction with Mr. H. Panton, on the actual power absorbed by various machine tools in doing their work. The figures are extremely interesting, as showing the very small amount of power absorbed by the different tools when doing their work.

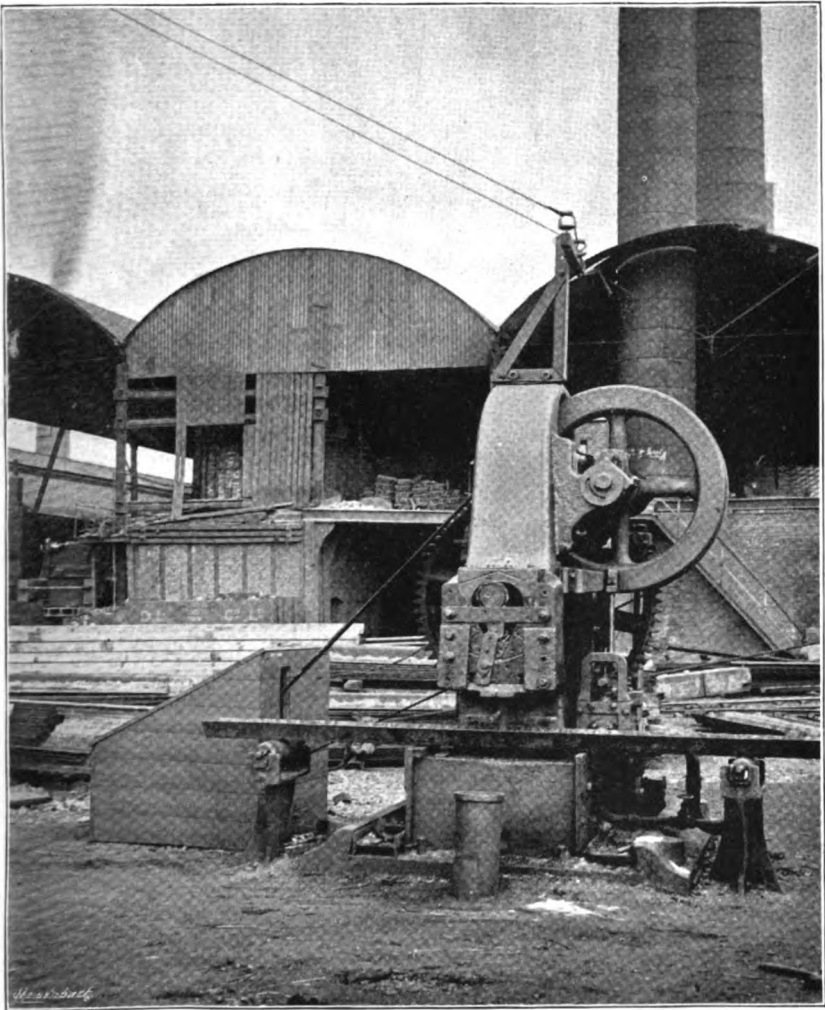
Table of Electric Motor Tests taken at the Works of Messrs. Dorman, Long & Co., Middlesbrough.—See Plates XXVIII., XXIX., XXX.

Description of Machine.	Driven by Engine Capable of Indicating	Replaced by Motor Capable of Indicating	Voltage at Gene- rator.	Voltage at Motor.	Current taken by Motor.	E.H.P. Absorbed in doing Work.
<i>Group of Machines as under—</i>	H.P.	H.P.			Amperes.	
Three cold saws	27	10½	120	115	70	10·7
Two ending machines						
One saw sharpening machine	14	3½	120	118	12	1·9
Troughing straightening machine	14	5	120	115	25	3·7
Double-ended punch, punch- ing four holes one side and one other						
Straightening machine, all sections	14	3½	120	115	15	2·3
Straightening machine, biggest sections	16	3½	120	115	35	5·4
Cold saw, 26 inches diameter	9	3½	120	110	15-27	2·2 & 3·9

The saving in coal effected on above machine tools amounted to 30 tons per week, after the adoption of the electric system.

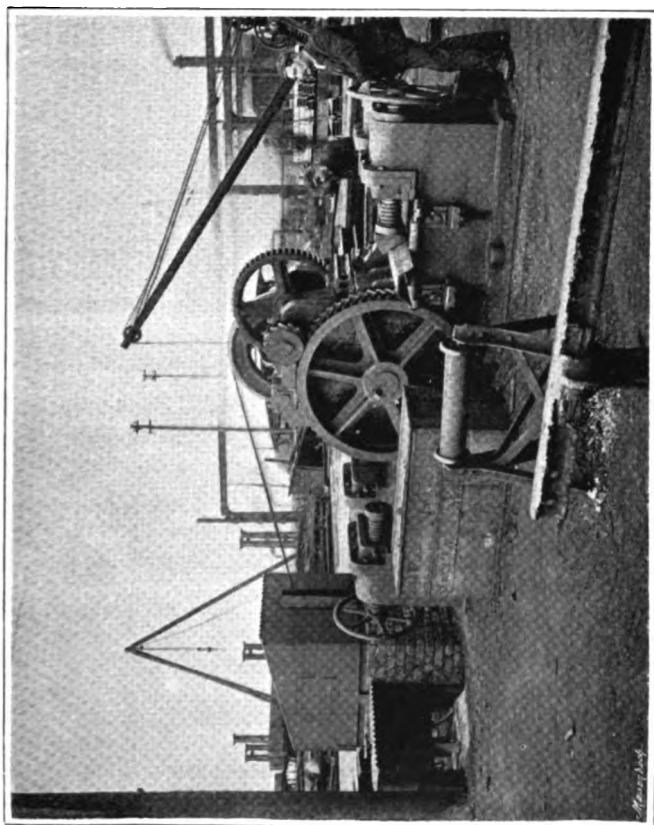
The author now wishes particularly to draw the attention of engineers to the concentration and distribution of power in works by means of electricity, and in order to fully demonstrate his ideas on this subject he has had two diagrams prepared (see Figs. 1 and 2, Plates XXXI. and XXXII.), one showing the various cases of power transmission one meets with at an old works, and the other showing the way in which these works could be remodelled, and what savings

PLATE XXVIII.

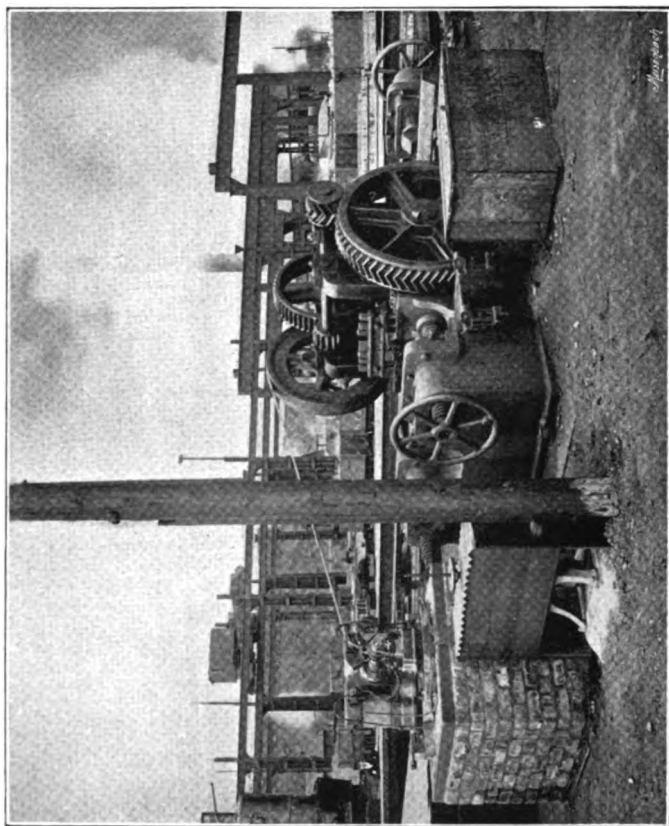


Electric Power Application at the Works of Messrs. Dorman,
Long, & Co.

PLATE XXIX.



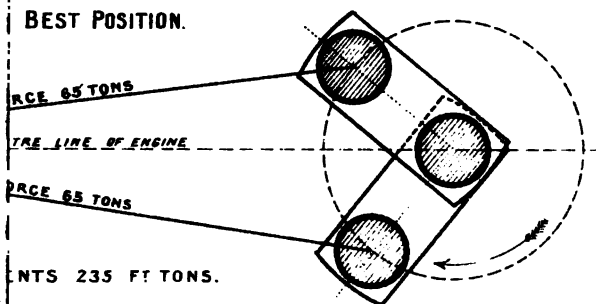
Straightening Machine driven by Electric Motor.



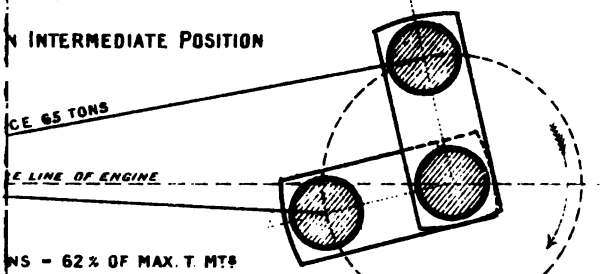
Straightening Machine driven by Electric Motor (cover removed).

H O

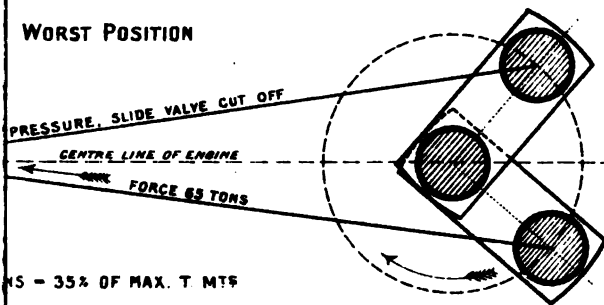
BEST POSITION.



IN INTERMEDIATE POSITION



WORST POSITION



could be effected by a judicious application of electric power. Of course the works represented above are purely imaginary, but it will be found that almost any works will contain some or other of the examples of power transmission depicted on this plan. The plan contains examples of power transmission met with in iron and steel works, engineering shops, shipbuilding yards, &c. In the case of the old works there are examples: (1) Of a large number of scattered steam-engines; (2) long lines of shafting and belting in the various shops; (3) considerable lengths of steam-pipes; (4) separate and scattered groups of boilers; (5) low-pressure steam; (6) old or uneconomical engines, especially in the smaller sizes; (7) intermittent character of the work.

Turning back to these cases, it is very evident to all engineers the great economy which would be realised if all these scattered engines could be concentrated in one large and highly efficient engine. The amount of coal taken per unit of work done would necessarily be very much less, and in replacing these engines by electric motors the services of a large number of men could be dispensed with.

Taking the second case of shafting and belting, the author thinks that few engineers really realise what is actually lost in the transmission of power through long lines of main shafting, counter shafting, pulleys, belts, &c. The power lost has often been ascertained to vary between 30 and 69 per cent. of the total power transmitted.

Fig. 3 represents the load-line of a motor when running in a shop in which a large number of small lathes, drilling and planing machines are at work, and is particularly interesting in one respect, namely, that more power is absorbed when the whole place is running light than when the normal work is going on. This will appear paradoxical at first sight, but it must be remembered that during normal working a large number of the machines are being stopped and started very frequently. The lowest line of the diagram shows the percentage of the total power absorbed in friction, the highest line, the amount of current taken with all machines running light, and the average of the varying load-line will give the amount of power taken when the shop was doing its normal work. This experiment

was repeated in different shops of a similar nature, and with different motors, and always with the same result, thus placing the truth of the diagram beyond dispute.

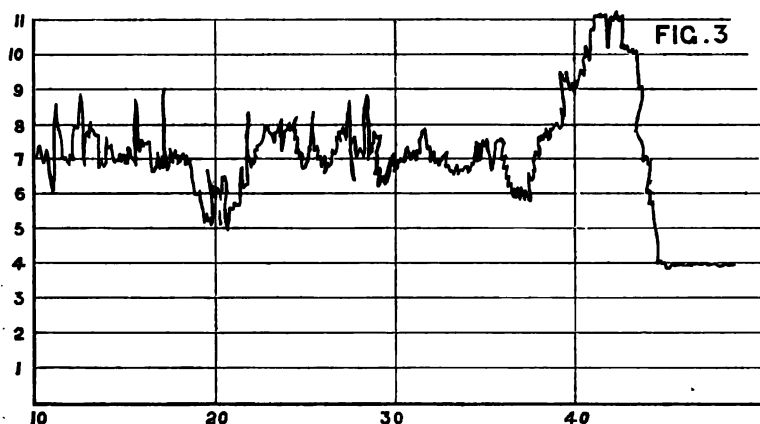
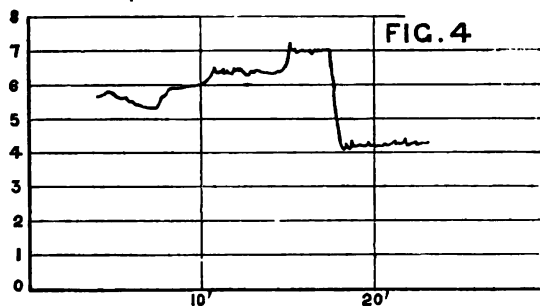


Fig. 4 shows the power absorbed by lathes or similar tools when they are running light, and when the cut is actually put on the metal they happen to be turning, thus showing what a small proportion of the power is expended in doing the actual work. The lower line again shows the proportion of current absorbed



in the shafting, belts, pulleys, bearings, &c., which, it will be noticed, is very large.

Fig. 5 is taken from an electric motor running a large number of drop-hammers, and shows very clearly the intermittent nature

of the work. This in no way affects the motor, and it is not even provided with a fly-wheel.

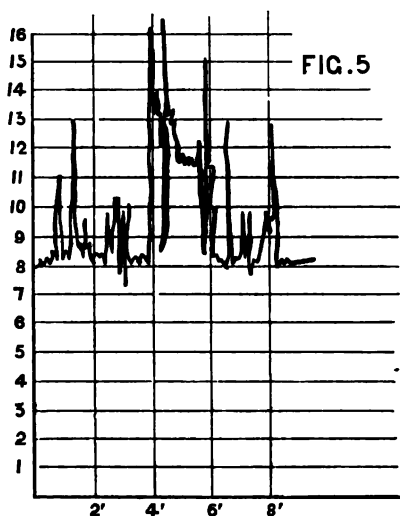
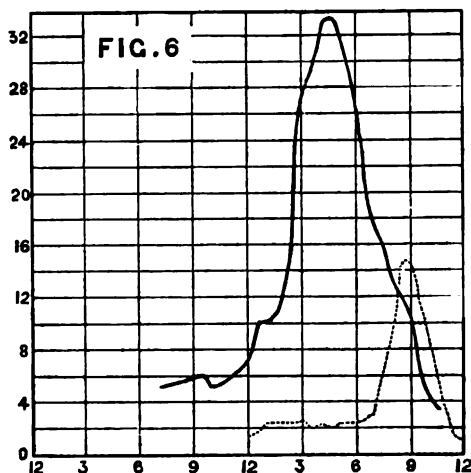


Fig. 6 shows the load-line of an electric lighting station, and by comparing it with fig. No. 3, the difference in form will



be at once observed. This bears on the class of generating machinery to employ.

In the case of long steam-pipes, it is a difficult matter to entirely prevent condensation, and one is always liable to leaky valves and joints. With separate boilers, this of course entails extra men to attend to the firing. With low-pressure steam, it is impossible to use the economical class of engine one could do with high pressures. In many large works the auxiliary engines are often found to be of an uneconomical nature. The work carried out is frequently of an intermittent nature, and machines which should be stopped when not in use are left running.

The author will now proceed to demonstrate a manner in which these old works could be entirely remodelled so as to effect an enormous saving both in coal consumption, wages, and upkeep.

The first thing to be done is to make a general survey of the whole works, and to have as many engines indicated as possible. Where this cannot be done it would be advisable to lay down a small temporary installation of an engine and dynamo, with a motor which could be transferred from one machine to the other, in order to ascertain accurately the exact power absorbed by the machine in question. In this way an accurate opinion could be formed of the amount of power actually required for operating the different machines throughout the works.

Having arrived at the total horse-power absorbed by all the scattered and outlying machinery, it is advisable to divide this into, say, two units of power. If the total power involved is 1000 horse-power, this would mean that it would be advisable to have two units of 500 horse-power each.

The reason why so large a power is selected as unit is that in electric power installations the load diagram will be found to be of quite a different nature to that of an electric lighting station, which exhibits a more or less constant rise and fall according to the time of day, whilst the load line in an electric power station is of a very different and fluctuating nature, varying at times between a quarter and full load, half load and full load, and so on. It is necessary, therefore, both for simplicity in working and for economical reasons, to have a steam dynamo capable of giving out current for at least half the installation. It would be necessary in the case of the five small machines to keep them all running, even if the load was only 25 per cent. of the total, in

case at any moment the load should suddenly rise. This practice has been adopted in nearly all large power installations on the Continent, and the author cannot help feeling that it is the right one.

In the case of works where waste furnace gases are available, the evident site for the generating plant would be in close proximity to these furnaces, in order that the boilers of the generating plant might be fired by the waste gases, the cost of the production of the electric current being thereby reduced to a minimum. Should there be no waste furnace gas available, the generating plant should then be placed close to the main battery of boilers in the works, and if these boilers are of a pressure below 80 lbs., it will be found economical to lay down entirely new boilers of say 150 to 180 lbs. pressure.

Having settled on our site, the next question to be decided is the form which the generating plant should take. In the case of a unit as large as 500 horse-power, one out of three alternatives may be resorted to; a compound condensing Corliss engine running at 80 revolutions per minute, with a multipolar dynamo, built up after the Continental fashion with the armature forming the fly-wheel of the engine, may be employed. Great confidence may be placed in a plant of this description, but the initial cost is comparatively a large one, owing to the large dimensions of the dynamo, and the slow speed at which it runs. If this speed were doubled, and an engine running at say 160 revolutions a minute taken, it would be possible to employ a triple expansion marine engine provided with condensing arrangements. A great reduction will be effected in the cost of the dynamo, and an engine of this type should work with great economy. It will be found necessary, however, to provide this marine engine with proper automatic expansion and regulating gear, owing to the variations in load and the necessity of absolute steadiness in running. The third alternative is still further to increase the speed of the dynamo, and to employ an engine of the high-speed type, similar to those adopted in many of our electric lighting stations. These engines would run at about 300 revolutions per minute, thereby doubling the previous speed of the dynamo, and again reducing its cost. These high-speed engines would be of the triple expansion type, and provided with condensing arrangements. Their consumption should not

exceed 15 lbs. of steam per indicated horse-power per hour. In any case, the plant to be laid down should be of the steam-dynamo type, that is to say, steam-engine and dynamo combined on one and the same bedplate, and direct coupled.

Having taken a decision as regards the generating plant, it is necessary next to consider the actual application of the electric motors themselves to the various machines, and the distribution of the power generally. According to the character of the works the main conductors would be carried either overhead or in a culvert underground, and, in order to keep down the cost, should be, if possible, bare copper, uninsulated. As works which have not a greater extension than 300 or 400 yards in length are now under consideration, the voltage which will be employed will be of a low tension.

In this manner can not only the whole of the power be run off the one single generating plant, but the entire lighting, both arc and incandescent, of the works themselves. The author considers that the voltage in such a case should be 120 volts. If the distances are too great to allow of this, owing to the expenditure in copper, the voltage could be increased to 500 volts. In iron and steel works, however, the low voltage is for many reasons preferable, as it is far easier to maintain a high insulation on a low voltage system than it is when a high voltage is employed. In all cases where new machinery is ordered for extensions or otherwise in the works, it would be preferable to embody the electric motor in the actual construction of the machine tool itself. In the case of old works, this is hardly feasible, and the next best thing to do is to drive direct by belt on to the fly-wheel of the machine in question. The motor itself, in the case of machines having to start up against any sudden or heavy load, should be of the shunt-wound type, with the shunt coils permanently excited off the line. Every motor should be provided with a starting and stopping resistance switch, by means of which the current could only be thrown gradually on to the machine, thus ensuring slowness and steadiness in starting up, and avoiding any sudden rises of voltage in the magnet coils, owing to instantaneous breaking of the circuit. Every motor should be enclosed with a suitable covering to protect it from damp or dust, and should, if possible,

be kept under lock and key, only an authorised attendant having access to the motors. The author has found the use of carbon block brushes almost indispensable with motors, and especially with those that have to run in both directions. The oiling arrangements of every motor should be perfect.

Supposing that the whole of the outlying machinery is actuated by electric motors, and that motors have been substituted for the engines and boilers on the overhead and locomotive cranes, that the driving power in the fitting shops and other places where shafting is employed has been split up, and that separate motors have been applied to the various countershafts, the following are the practical results which will have been obtained by remodelling the old works on the lines described and shown in diagram No. 2.

Coal Consumption.—The total efficiency of the new installation, provided that the distances involved do not exceed 500 yards, should attain 75 per cent. The loss of 25 per cent. would be made up as follows:—

	Per Cent.
Loss in main generating dynamo	7
Loss in the mains	3
Loss in the motors	15

In many works where the engines are very much scattered, it will be found that the coal consumption per horse-power of work turned out will amount from 8 to 15 lbs. of coal and even more. Although a great reduction in the coal consumption will be effected through the use of the improved class of machinery employed and means for transmitting the power generated, there is another way in which the coal consumption can be further decreased, and that is by the instantaneous switching off of the motors when not in use. Many of the outlying engines in the old works will no doubt have been left running when not actually employed; and even when not running a considerable quantity of steam may have been escaping from them or from the steam-pipes leading to them. Unlike steam, the moment a motor is switched off, electric current ceases to be generated, and the small loss in conveying the power through cables instead of steam-pipes is a matter evident to every engineer. In the case of the remodelled works, the coal con-

sumption at the end of a year's work will probably be found to be one-half, or even less, of what it was previously, before the adaptation of electricity.

It is advisable that in every case the electric lighting of the works should be combined with the power, current for the lighting being obtained from the same generating dynamo. In looking at the total coal consumption, it must be remembered that a considerable proportion of this goes towards the electric lighting. Previously the works may have been lit either by gas, oil, or lucigen lights. In the case of the remodelled works, the lighting would be carried out in the yards by means of arc lights, in the fitting and engineering shops by means of inverted arcs, and in offices and such places where arc lighting is not suitable, by means of incandescent lighting. The cost of coal consumed in producing electric light for the whole of the works, should compare very favourably with that of gas and oil lighting previously employed.

Wages.—The next point to be considered is that of wages. It is evident that by the entire suppression of the scattered boilers, the services of a considerable number of stokers can be entirely dispensed with. This is also the case with those steam-engines which require an engineer to run them. It is also probable that more men will have been employed in looking after the gas and oil lighting, than will be required for the electric light. The motors can be kept practically under lock and key. Should anything go wrong with them, this will be at once indicated on the instruments in the engine-room, and an attendant can go from there to see what is the matter. The motors, therefore, in no way involve the necessity of special attendants, and one man to see that they are properly oiled and the brushes set, is all that is required. For powers up to 500 horse-power, one stoker, one engineer, and one electrical attendant, is all that should be required at the generating station per shift. It will therefore at once be seen, in comparing diagram No. 1 with diagram No. 2, that the wages of a large number of men could be entirely dispensed with, owing to the application of the electric system.

Upkeep.—We have now a further point to consider, and that is

the question of upkeep of such an electrical installation. The upkeep on electric power installations which have already been running over three years, involving the use of a large number of motors, arc lamps, &c., has proved that this can be safely estimated at something under 5 per cent. on the total capital expenditure of the electric installation. No hard and fast rule, however, can be laid down for the exact cost of upkeep, as this must necessarily vary with the different classes of works to which electricity is applied. It is clear, however, that the maintenance of bare copper conductors must be very much less than that of a large system of steam-pipes, lines of main shafting, ropes or belts, which have hitherto been employed as a means for transmitting the power, from the generating source to the spot at which the power is actually applied. The depreciation on the copper cables should therefore be very small. As to the upkeep of the electrical machinery itself, nearly everything depends on the cleanliness with which this is kept. If properly attended to, the only wearing parts requiring renewal will consist of bearings, brushes, and commutator, all of which can be replaced for a very small outlay. These renewals compare very favourably with renewals in steam-engines, shafting, gearing, &c. The cost of upkeep of a well-considered electric power installation should therefore be very low; and, indeed, many proofs are forthcoming that this is actually the case.

Control.—The author thinks that one of the most important features in connection with electric power installations is the absolute check or control one has over the coal consumption and running expenses at the works. It is advisable, where possible, that circuits from all motors or groups of motors should be taken direct to the generating station, that on each of these circuits a separate ammeter should be placed, which will indicate the exact power taken by any of the machines at any time of the day. With a little practice, the man in charge at the engine-room can tell from the various indications on the measuring instruments almost exactly what the various machines in the works are doing—whether standing idle, or whether working up to their full power or not. By means of an automatic registering ammeter placed in the main dynamo circuit, the total amount of

power going off into the works will be recorded on a card; and the coal consumption for the day having been kept, the cost of production per unit of electrical energy can be ascertained. Owing to the self-indicating nature of electric motors, in this and other ways, can a most perfect check be kept on the running expenses of the electric power plant, and the slightest loss due to leakage or undue resistance in any part of the electrical apparatus can be at once detected and remedied.

Rolling-Mills.—It is quite within the bounds of possibility that electricity may find a new opening in its application to driving the lighter class of rolling-mills. The result, as far as economy in steam consumption is concerned, would show a great saving on methods formerly employed. The saving would be arrived at in the following manner:—Instead of the present form of engine used for actuating the rollers, which is necessarily of a somewhat uneconomical nature owing to the work it has to perform, and in which the cut-off is of a very imperfect character, a triple expansion engine could be laid down on the most highly economical principles, working at a high pressure, and taking not more than $1\frac{1}{2}$ lbs. of coal per indicated horse-power per hour. This engine would be coupled direct to a dynamo of suitable power, and the steam dynamo generator would be kept running continuously. On each set of rolls would be directly coupled an electric motor. The switching apparatus would be worked by means of hand and foot levers, almost in identically the same manner in which the steam is shut on and off existing rolling-mill engines.

An electric motor may be considered as an elastic coupling in itself, and provided that the power furnished to it is sufficient, it will revolve when the necessary torque has been obtained. The jar, however, would be furthermore reduced by mechanical methods of coupling, and the writer does not anticipate any difficulty in being able to obtain a motor which would resist such strains as would be put upon it. The switching apparatus, however, would require carefully planning out and constructing, in order to withstand the rushes of current which would take place through the apparatus, but here again there is nothing that cannot be overcome.

The main advantages, however, to be derived from the electric system, would be the following:—

1. The question of dead centres would be practically eliminated. An electric motor in itself, unlike a steam-engine, having no dead centre. The main engine driving the generating dynamo being kept continuously running, the difficulty of dead centres would be overcome there also, the result being that the total size of the engines employed would be considerably reduced, as in the present case it is necessary that either cylinder of a rolling-mill engine should be capable of starting the rolls from nothing to full load, in case one of the engines should be on its centre.

2. Owing to this new arrangement of driving, a totally different class of engine could be employed to what is now used, and instead of using 7 to 8 lbs. of coal per indicated horse-power, owing to its imperfect cut off, the coal consumption should be reduced to $1\frac{1}{2}$ lbs. per indicated horse-power.

3. A considerable number of small mills could be actuated in totally different parts of the works by means of the one generating engine and dynamo, and would thus save wages and upkeep over several smaller engines scattered about.

4. The whole of the auxiliary engines required for working the live rollers, elevating, or transverse gear, overhead cranes, &c., could be replaced by electric motors all worked off the one generator.

5. Great economy in steam consumption owing to concentrating the production of the power in one spot, under highly efficient conditions.

In speaking of the above applications the author does not, of course, refer to the heavier class of rolling-mills, which absorb several thousands of horse-power, but firmly believes that as regards the lighter class of mills there is a future for the application of electric power, the great advantages to be derived being the large economy which could be effected in coal consumption and wages.

The author now wishes to supplement this by some further information on rolling-mills with reversing engines which he has obtained through the courtesy of Mr. W. H. Pantou, and some figures which Mr. Crowe has kindly given him.

Comparison between the ordinary two-cylinder direct reversing mill engine, and a reversing mill driven electrically :— The possible indicated horse-power of the usual two-cylinder direct coupled reversing mill engine greatly exceeds the horse-power actually developed, for the reason that the engine must start from rest, with the piece just entered in rolls, no matter what position the cranks may happen to be in. Taking the cranks in their most favourable position for exerting their greatest turning moment, and calling this 100, then when the cranks are in the most unfavourable position, the turning moment is only $41\frac{1}{2}$ per cent. If the turning moments of the engine shaft could be equal, it is quite evident that an engine of less power would do the work. Taking, for example, a two-cylinder reversing mill engine, with 48 diameter cylinder by 54 stroke, 80 lbs. steam on piston, cut-off at $\frac{8}{10}$ the stroke, the indicated horse-power at 60 revolutions would be about 4800. When the cranks are in their best position, the twisting moments would be 235 foot-tons, and in their worst position only 97.5 foot-tons. As the twisting moment of 97.5 foot tons is sufficient to start the piece, it is evident, if the power represented by that twisting moment were constant, it would drive the mill. This power would be only 2490 horse-power. If the mill were driven by a motor, whose torque is of course constant, the horse-power of the motor need only be, say, 2400, or one-half of the two cylinder reversing engine. Allowing for losses in the motor, dynamo, and the line, the indicated horse-power of the engine driving the dynamo would be 3000, as against 4800 for the reversing engine. The great economy in fuel would lie in the use of a triple-expansion condensing engine, using only one-third or one-quarter the steam used in the reversing mill engine, with their necessary very late cut-off, giving practically no expansion of steam. This means a reduction in the coal consumed of about 60 per cent. (see Plate XXXIII.).

There is another point that should be taken into consideration when laying down an electric power installation, and that is, the small size of the motors themselves, which, owing to their rotary and not reciprocating motion, only require light and inexpensive foundations. The same thing applies also to the foundations required for the central generating plant.

Engineering Works and Shipbuilding Yards.—The same arguments apply to the application of electricity to engineering shops and shipbuilding yards as have already been cited. In shops where the work is of a very intermittent nature, it would be an economy to drive the larger machine tools by separate motors, and there is no doubt that in the near future manufacturers of machine tools will turn their attention to embodying the electric motor in the actual construction of their tools. Where the tools are of a lighter character, economy will result from doing away with the main shafting, and applying motors at the intersection of this with the secondary lines of shafting, and in other ways subdividing the power and running the various machines, as far as possible, independently one of the other.

The following table, calculated by Mr. Félix Mélotte, shows a very interesting comparison between the efficiencies, obtained on a varying load, of electrical and mechanical transmission of power:—

<i>Electrical Transmission—</i>						
Load on the engine	1000	750	500	333	250	200
Constant frictional loss	50	50	50	50	50	50
Variable electrical loss	50	27	11	4.5	2.2	1.2
Total loss in dynamo	100	77	61	54.5	52.2	51.2
Available power of dynamo	900	673	439	278.5	197.8	148.8
Efficiency, per cent.	90	89.7	87.8	83.5	79.1	74.4
Loss in conductors	18	10	4	1.7	0.8	0.5
Energy available at motor terminals	882	663	435	276.8	197	148.3
Of which, 6 per cent. frictional loss	53	53	53	53	53	53
4 per cent. variable loss	35	20	8.5	3.4	1.7	1
Total loss in motor	88	73	61.5	56.4	54.7	54
Power available	794	590	373.5	220.4	142.3	94.5
Final efficiency, per cent.	79.4	78.7	74.7	66.2	57	47.2
<i>Mechanical Transmission—</i>						
Load on engine	1000	750	500	333	250	200
Loss in shafting, &c.	206	206	206	206	206	206
Useful effect	794	544	294	127	44	0
Final efficiency, per cent.	79.4	72.5	58.8	38.1	17.6	0

From this table it will be seen that the two systems of transmission, which at first appear to be equivalent, become very different as the load diminishes. Thus, when only one-fifth of the power is developed, electrical transmission still yields 47.2 per cent., whilst mechanical transmission has had all its

power absorbed in the constant frictional loss of 206 horsepower.

In shipbuilding yards there are few machines that cannot be run electrically. The whole of the machinery usually found in the machine sheds, such as punching, shearing, bending machines, &c., saws, wood-working machinery, can all very easily be run by electric motors. Owing to their light and portable nature, there is a considerable opening for electric machines on board ships during construction. Electric power can be utilised with advantage for the drilling of ships' plates, temporary winch and derrick crane work. The author understands that it has also been successfully applied for planing wooden decks.

Results obtained.—There are few works in this country, if any, that are solely actuated by electricity. The principal applications of electric power for driving works, up to the present, may be found in the workshops of electric manufacturers themselves, who have naturally had more opportunities for investigating the advantages to be derived from electric driving.

In order to give some idea of results actually obtained in the running of works for a considerable period, the author will take some figures from electric power installations carried out in Belgium, which have now been running some three years, cases in which the entire works have been actuated solely by electric power. This information may possibly be of interest to the members of the Iron and Steel Institute, who before long will be paying a visit to Belgium. One of the first, and perhaps most important, electric power installations that has been laid down in that country, is that of the National Arm Factory at Herstal, near Liège. It would be impossible in this paper to deal with a full account of this installation. The plant in the first instance consisted of a 500 horse-power compound Corliss engine and multipolar dynamo combined, the armature acting as fly-wheel of the engine. The Arms Factory is solely and entirely driven by electricity derived from this one dynamo, which provides at the same time the whole means of illuminating the works. Until about nine months ago there was no other engine or dynamo on the place. Some 2000 hands are employed, and have been dependent for over two years on the running of this one dynamo.

There has been no stoppage from the day of starting the installation up till the present time. About nine months ago another 300 horse-power was put in. This, however, was not to act as reserve power, but to supply power for extensions which had been made to the factory. The steam consumption of the engine is 13 lbs. of steam per indicated horse-power. The total efficiency, reckoning from the indicated horse-power of the engine, has proved itself to be 71·3 per cent.

Following the example of the National Arm Factory, the Belgian Government decided to remove all the steam-engines and boilers from the Royal Arm Factory at Liège, and to replace them by electric distribution. It was ascertained that for a certain portion of the work which, previous to the introduction of electric driving, had taken 3 tons of coal per day, this was found to have immediately come down to 900 kilogrammes, or less than 1 ton, for the same amount of work done.

About a year and a half ago a 100 horse-power dynamo and six or seven motors were laid down at the glass works of the Val St. Lambert, Belgium, the total efficiency attained coming out to 75·5 per cent.

At the zinc works of the Veille Montagne Co. a large electric power installation has lately been laid down, by means of which these old works will be entirely remodelled, every engine and boiler on the place being done away with. The power at present installed consists of a 600 horse-power dynamo and compound Corliss engine combined, running at a speed of 80 revolutions per minute, and wound for a voltage of 500 volts. The following are the number and sizes of the motors employed in this installation :—

5 motors of		1	horse-power.
7	„	2	„
6	„	3½	„
6	„	5	„
4	„	7	„
2	„	10½	„
4	„	14	„
2	„	45	„
1	„	64	„

The following additions are now being made:—

1 motor of 80 horse-power.

1 " 14 "

5 " 1 "

1 " 10 "

Another section of 600 horse-power is provided for. The engines have been specially built by the Société Cockerill, and the dynamos by the Compagnie Internationale d'Electricité, under the direction of their chief engineer, Mr. Henri Pieper. Babcock & Wilcox boilers are used, and the steam-engine takes from 13 to 14 lbs. of steam per indicated horse-power. The efficiency of the engine is 90 per cent., that of the main generating dynamo 90 per cent. at full load, and the efficiency of the distributing cables, also at full load, is 98 per cent.; the average efficiency of the motors is 86 per cent., and the commercial efficiency of the whole installation is therefore 68·5 per cent., that is to say, the proportion of work done to the indicated horse-power of the steam-engine. A continuous-current transformer is used to reduce the voltage from 500 to 100 volts for lighting purposes.

Several works in Germany and Switzerland are also operated solely and entirely by the electric system.

CONCLUSION.

Taking into consideration all that has been stated in the preceding pages, it will be seen that electric power is destined in the near future to become an important factor in the iron, steel, and engineering trades. Whether applied for the purpose of long distance transmission at the mines, or for short distance transmission and concentration of power at works, great economy will be realised in wages, fuel, and upkeep, over methods hitherto employed. Old works can be remodelled with advantage, as shown in the cases of the Royal Arm Factory and the Veille Montagne Zinc Works in Belgium, and the case of Messrs. Dorman, Long & Co.'s Steel Works at Middlesbrough, and what possibilities lie open to those contemplating laying down entirely new works! The author was fortunate a few months ago to come

across a company who were about to lay down entirely new works, and finally succeeded in getting them to promise to look into the electric power question thoroughly before taking any definite decision as to what power they would adopt for their works. Some four months were spent in visiting power installations in this country and abroad, and the electric system was minutely compared with steam and gas, actual experiments were carried out, with the result that the Bedson Wire Company finally decided on adopting electricity as their sole power for manufacturing purposes.

These works in many respects are so entirely novel, the question of economy has been so minutely gone into, that the author believes that Mr. Bedson, in the course of a few months, will be able to publish a record in working efficiency and steam consumption which has seldom, if ever, been equalled. Messrs. Bell Brothers, of Middlesbrough, who have also been taking great interest in the electric power question for some time past, are installing electric power at their Clarence Works.

There are, no doubt, many of the author's colleagues in electrical work who could add many interesting examples of electric power applications in this country.

The author trusts that in the foregoing paper he has shown that electric power has passed out of its experimental stage, and should he have been so fortunate as to have provided a subject worthy of interest, and subsequent discussion by the Iron and Steel Institute, his task will have been amply accomplished.

CORRESPONDENCE.

Mr. A. G. CHARLETON considered the author's paper one of exceptional interest to engineers—not only to those engaged in the iron and steel industries, but to many who, like himself, were more particularly connected with other branches of metal-mining at home and abroad. As an example, he would mention that, whilst recently engaged in laying out a large mining and dressing plant in the Pyrenees, he was very much struck by the immense use to which electricity might be applied in several different ways.

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1. To drive the machinery at the mine, which was situated at a high altitude, in a position rendering it somewhat inconvenient and indeed difficult, to employ steam or other forms of power-transmission.

2. For lighting the works.

3. For the magnetic separation of the ore—the employment of electro-magnetism rendering it possible to produce a marketable zinc-blend from low-grade material (carrying magnetic iron), which would otherwise have been unsaleable.

There was, however, it should be mentioned, the very great advantage of splendid water-power in the neighbourhood conveniently situated to operate turbines or Pelton wheels for current-generating purposes. Until he read Mr. Selby-Bigge's paper he was certainly under the impression, however (as he believed most engineers were), that where the advantage of water-power could not be commanded, electricity was in most cases only commercially applicable for *long-distance* transmission. The economy which should result where steam was used, both in fuel consumption and labour, with the various minor advantages the author claimed (through laying out works in the manner he suggests), had indeed not impressed him with the force they now did, in view of the very clear manner in which the matter was put in his paper.

One paragraph in particular was of special interest—namely, that “few engineers really realise what is actually lost in the transmission of power through long lines of main-shafting, counter-shafting, pulleys, belts, &c. The power lost has often been ascertained to vary between 30 and 69 per cent. of the total power transmitted.”

In a paper recently read before the North of England Institute of Mining and Mechanical Engineers, “On the Choice of Coarse and Fine Crushing Machinery and Processes of Ore Treatment,” he took occasion to say “that it appeared to him we must look for advancement in the future rather towards perfecting the details of the machinery and processes we at present possess, than to the discovery of new principles.

“We might substitute, for example, a small motor of the Diehl type for the fly-wheel, belt, and pulley of a rock-breaker, or other

machine, and *drive it direct in this way, perhaps with advantage in some situations.*"

Now, when he made that suggestion, he was entirely unaware that anything had been done practically in this direction, and he was extremely glad to find the feasibility of the idea confirmed and actually applied on a large scale, where power had to be distributed amongst a number of machines and belt transmission was inconvenient or costly. The advantages of electricity for power-transmission were daily becoming better recognised in the mining districts of the Western States of America, in localities where water-power could advantageously be turned to account.

In that connection it might possibly be of interest to members of the Iron and Steel Institute if he mentioned what had been done in two notable instances.

I. The plant of the Aspen Mining and Smelting Company of Pitkin, Colorado, which was the first mining company in America to use electrical power for hoisting. The mines where this plant was erected were situated on the north-west flank of a mountain which presented a slope of about 28°.

The ore, which was found at the contact of a mass of blue limestone with an underlying bed of dolomite, dipped north 30°, west at an angle of 60°, and was reached by an adit (driven south into the mountain at a vertical depth of some 500 feet) about 1000 feet in length, given a grade of 3 in 100, which was used for both drainage and transport. In order to develop this ore-body, drifts were run right and left from the inner end of the adit-tunnel along the strike of the deposit, and two incline-planes were sunk with the idea of sinking them to a considerable depth. One was begun near the inner end of the adit-level, the other 300 feet distant in the drive north of it. Power of some kind being necessary to raise the ore and waste materials ("deads") to the main-tunnel level, it was decided to try electricity, as both steam and compressed air offered serious objections. Accordingly a "flume" was constructed to carry the water of the neighbouring mountain streams to a 5-foot Pelton wheel, under an effective head of 63 feet, and a 50 horse-power 500 volt constant potential Edison dynamo was installed in connection with it, at a distance of 6000 feet from the mouth of the tunnel. The hoist, which consisted originally of a 7½ horse-power street-car-

motor manufactured by the Sprague Electric Railway and Motor Co., was placed at the head of the Veteran tunnel July 1888, and was provided with an auxiliary drum to draw the empty cars in the tunnel by a tail-rope system, the loaded train running out by gravity. Notwithstanding the trying conditions under which this plant was operated, one of which was the condensation of moisture on the machine, owing to the dampness of the workings, it proved a success. The iron pinions on the armature shaft were, however, exchanged for raw hide pinions, which diminished the noise when running, and the liability of leakage of current to the levers and other parts of the machinery, and it worked so successfully that a second hoist was placed at the head of the other incline. Each of these hoists was designed to raise 250 tons, 250 feet up a 60° incline every twenty-four hours, reckoning sixteen hours' actual work. The original motor had been in use for three years in the autumn of 1891, during which time the cost of repairs is stated to have been as follows:—

	£	s.	d.
Replacing field-magnet coils	8	6	0
Rewinding one armature	16	0	0
Replacing commutator	15	0	0
	<hr/>		
	39	6	0

That statement did not include the small item of commutator-brushes, the copper brushes first employed being responsible for the last item of repairs mentioned. Since the adoption of carbon-brushes the motors have run without "sparking," and the wear upon the commutators was inappreciable. The burning-out of the insulating material on the field-magnet coils might have resulted from one of several causes, whilst the bursting of the binding-wires on the armature could have been guarded against had it been anticipated. An extra armature that can be used in either motor-hoist was now, however, kept on hand in case of accident. The total time lost in making the repairs alluded to was twelve hours. In 1890 the Aspen Company decided to erect a generating plant of its own (the original one, belonging to R. F. Electric Light and Power Co.), and they erected for this purpose four 42-inch Pelton wheels, set in pairs on the same shafting. Each wheel was actuated by a double nozzle, which discharged the water in two

streams, at a pressure of about 35 lbs. per square inch, obtained by utilising an effective fall of about 80 feet. The flume which carried the water to the head of the pipe had a capacity of 1000 cubic feet per minute, and a length of 1300 feet. The plant was coupled to two 50 horse-power Thompson-Houston motor-type dynamos wound for a constant potential of 500 volts, generating 100 electrical horse-power. The power generated in this way was automatically regulated to the demand made upon it by deflecting the water-wheel nozzles (which work on a ball and socket joint) by means of a Woodward governor, set to maintain a constant speed of the water-wheel shaft from which it was actuated.

The wheels were enclosed in an iron hood 4 feet by 4 feet, which could be removed with little trouble, the joints being made tight with rubber gaskets. The adjoining ends of the water-wheel shafts carry a friction-clutch, by which they could be run as one, when it was desirable to apply the motive force of both dynamos to the one common line, and the dynamos were connected with the switch-board in the generating station by overhead wires hung from the trusses. The current was conveyed from the power-station to the tunnel 6000 feet by bare 0·0 copper wire, except for a short distance (about 300 feet) at the end of each line, where an underwriter's insulated wire of the same gauge was used. Inside the mine the current was conducted to the hoisting-stations, a distance of 1000 and 1200 feet, by Kerite seven-strand conductors, having a heavy insulation $\frac{1}{3}\frac{1}{2}$ inches in diameter. Okonite or Grimshaw insulated wires were used in all the circuits inside the mine, where the insulation must necessarily be of the best, and in none of the interior circuits was there a loss of more than 5 per cent. The loss on the outside circuit carrying the maximum load required, up to the time these particulars were given, was 5 to 6 per cent. The cost of generating current (not including interest or depreciations) obtained by dividing the cost of labour and lubricants by the horse-power required, was found to amount to $\frac{2}{3}$ of 1 cent per horse-power per hour, but greater amounts of power could be furnished at a lower rate per horse-power; as up to 100 horse-power no increase of plant would be needed, the cost of labour would remain the same, and the cost of lubricants would not be much increased. In July 1890, Mr. F. G.

Bulkley, the manager, put in an electric diamond-drill, operated by a 3 horse-power Thompson-Houston motor, designed to bore 400-foot holes $\frac{1\frac{5}{8}}{8}$ inch in diameter. It was used for twelve months to explore the hard blue, often silicified, hanging-wall of the Aspen mine, and the brown dolomitic footwall, and drilled, it is stated, at the rate of $1\frac{1}{2}$ to 2 inches per minute, or in a shift of eight hours, allowing for delays inseparable to such work, from 6 to 32 feet, depending on the character of the rock. The average progress, allowing for time lost in setting up and drawing cores, was put at 15 feet, and it was served by one man with a helper. 4400 feet were drilled by this machine from starting to July 6, 1891, at a cost, inclusive of all expenses, of 68 cents per foot. Subsequently a 25 horse-power C. & C. electric motor was substituted for the original $7\frac{1}{2}$ horse-power hoist erected at the head of the main incline. This machine was geared to raise a load of 3000 lbs. up a 60° incline 275 feet per minute, and had been proved capable by trial of making the round trip, from a depth of 550 feet, in three minutes, with the full load. Electrical power was now, he believed, applied at the mine to run a small machine-shop, saw-mill and wood-working machinery, and the company proposes to employ an electric locomotive for surface conveyance, and to make trial of a Thompson Van Depoele electric percussion drill, a motor-transformer supplying the drill with a current of 220 volts taken from the 500-volt mains. The main levels of the mine are lighted by electricity taken from the power-mains, employing five or six 100-volt incandescent lamps, connected up in series, which absorb about 8 horse-power electrical energy. Mr. M. B. Holt summarises the advantages of electrical power for mining operations in his account of this interesting installation* by remarking:—

1. That it can be transmitted long distances with small loss, thus making it possible to use power at such a distance from its source, as would render it otherwise unavailable, as in the case before us.

2. The conductors for conveying electrical power from one point to another require less space, are more easily put in place and repaired, are easily tapped for branch circuits, and form a

* *Transactions of the American Institute of Mining Engineers*, vol. xx. p. 323.

more flexible system throughout, than any other mode of transmission permits.

3. The electrical system is ideal viewed from the standpoint of cleanliness.

4. The stations for utilising electrical power can be made to occupy a minimum space.

5. If this system does not assist ventilation, it does not, on the other hand, vitiate the air in mine-workings.

6. After three years' use under varying conditions of mining work, the electrical current of 500 volts has proved itself to be free from danger to life, and has caused no inconvenience further than one or two severe shocks.

II. The second notable case he should like to instance was "the plant" of the Standard Consolidated Company of Bodie, California; they having lately erected an electrical-power plant to run their 20-stamp mill. In 1891 milling cost them on an average 3.89 (16s. 2½d.) per ton, crushing about 1309 tons per month, and, as the price of fuel was \$10 per cord in this locality, their fuel bills frequently exceeded \$2000 a month. On this account, and for other reasons, it was decided to try electricity. An excellent water-power was found at Green Creek, a mountain stream on the northern slope of Castle Peak in the Sierra Nevadas, forming one of the chief feeders of Walker River, and an arrangement was made for a perpetual right to its use, for power purposes, on very favourable terms. This stream carried 500 miners' inches of water at its lowest stage, and ran six or seven times that amount when the snows melt in "the spring." An old ditch was cleaned out, and practically rebuilt for a length of nearly a mile, and a site selected for a power-house, 355 feet vertically below the lower end of the ditch. The work of cleaning the ditch, building dam, head-gate, waste-weirs, flume, penstock, and power-house, and of laying and anchoring the pipe was pushed during the months of August, September, October, and in November 1892. The water-wheels were put in place, so that by December the water-power plant was completed and ready to run. A pole-line was constructed following a straight line, 12 miles in length, over the mountains from the power-house to the mill, upon which to hang the wires, and 14 miles of telephone line was built between the Bodie office and the

power-house, but at a distance from the power-line, in order to avoid induction and consequent bad service of the telephones. The motor foundations were also put in at the mill, and a motor-room 26 by 18 feet was built, whilst the necessary counter-shafting and pulleys for making the connection between the motor and battery-shafting were made ready to put in place. Lumber from the old Bulwer-Standard Mill and other material was used in the construction of the works at Green Creek, thereby greatly reducing the cost. The power-house, 30 by 40 feet in size, was the former mill salt-house, and the penstock was one of the water-tanks at the mill, while the steel receiver at the lower end of the pipe was made at the mine from an unused steam-drum. The ditch was 4558 feet long and was connected with the penstock by a short piece of flume fitted with the usual screen, sand-bore, waste-weir, and flushing-off gate. The pipe was led into the above-mentioned steel receiver (40 inches in diameter by 9 feet 8 inches long), from which four taper pipes carried the water under pressure of 350 feet vertical head to as many 21-inch Pelton water-wheels, each pipe being fitted with two nozzles and each wheel capable of developing $62\frac{1}{2}$ horse-power. The wheels ran at 865 revolutions, and the wheel shaft was connected by a patent insulating coupling to the armature shaft of a Westinghouse 120-kilowatt alternating dynamo generating current at 3530 volts. A Doolittle governor was attached to the wheels, and a No. 2 Pelton-motor had also been put in to run the "exciter" necessary for generating the initial current in the fields of the large machine. The poles of the line are of round tamarack timber 21 feet long, 5 inches in diameter at the top; 25 feet poles being used in the town and where the ground required it. They were spaced 100 feet apart, and fitted each with a 4-inch by 6-inch by 4-foot cross-arm, boxed into the top of the pole and fastened with one bolt and one lag-screw. The wire was No. 1 B. & S. gauge soft drawn bare copper, and was attached to standard double-petticoat deep-grooved glass insulators carried on Klein $\frac{3}{4}$ -inch by 8-inch pins. The wire used was of large section, but the distance of transmission was just at that half-way point where the cost of converters about equals the difference in price between a No. 1 and No. 6 wire, hence it was considered better to use a higher potential and a large wire, and avoid the complicated

and often troublesome converter. The loss of potential on the line was estimated at 15 per cent., and the current delivered to the motor will therefore be 3000 volts tension. The motor was 120 horse-power, and would be brought up to speed by a small motor of 3 to 4 horse-power, which was built on the same bed-plate as the larger one, and thrown out of circuit as soon as the latter was at proper speed, running in synchronism with the generator at the power-station. Two "transformers," ratio 30 to 1, of a capacity of 100 incandescent lights each would be used for lighting the mill and offices at Bodie. The cost of this plant was given as follows:—

Water-power, including ditch, pipe, water-wheels, &c.	£1783
Wire line (12·46 miles) £168 per mile	2095
Motor room, counter shafts, and pulleys at mill	358
Telephone line (14 miles) \$78.52 per mile	220
Sundry expenses	61
Dynamos and electric plant	2242
Total	£6759

The plant was not ready to run till October 1893, owing to various unlooked-for delays, but during that month it ran continuously with the exception of two days, and the saving effected was clearly shown by the cost of milling that month, viz., 9s. 8d. per ton, as against the average cost for the preceding eight months of 15s. 9d., a difference in favour of the electric power of 6s. 1d. The mill was operated by electric power all through December, effecting an almost equal saving, but trouble was experienced in November, and again in January 1894, due to the freezing of the water-ditch. In concluding his report for the year ending January 31, 1894, Mr. T. H. Legget, the manager, says, "We have the advantage now of being able to operate the mill by electric power, enabling us to work a higher grade and less quantity of ore without the loss of time and money accompanying each start and stoppage of the mill when the same is being driven by steam power; this aside from the direct saving in fuel consumption of from £7 to £8 per twelve-hour shift."

The idea of utilising the surplus waste gases of blast-furnaces for firing boilers to generate electrical work in districts like Cleveland appeared to be a very valuable one, capable of large practical

application. The absolute checks over the coal consumption and running expenses which electric power afforded, indicating exactly what the various machines in the works were doing, were certainly features which should recommend it to consideration.

Mr. L. RICHARDS, referring to that portion of the paper dealing with the application of electric motive power in place of steam at the blast-furnaces, steelworks, and rolling mills, thought that the author overrated the amount of the waste gases that would be available after the requirements of the blast-furnaces had been supplied. But would there be any advantage derived from the use of electricity as a motive power, rather than steam, in the blast-furnace department, beyond possibly driving overhead and perhaps other travelling cranes, and, of course, the lighting? Pumping water for lifts and other hydraulic machines constituted most that was to be done by motive power outside of the blowing engines. In pumping machines generally the motive power was made to produce rectilinear motion direct, rotary motion playing only a small part, that was to say, the pressure of the steam on one piston was made to act direct upon another piston, or plunger, as the case might be, so as to force the water into the accumulator and the tanks, a light fly-wheel in some instances having been used to clear over dead centres, and to insure regular running. It was difficult to see how any advantage was to be gained by the substitution of electric motive power for that of steam direct in machines of that class.

Coming to the steelworks and rolling mills, the author stated that the coal consumption per horse-power of work turned out was from 8 to 15 lbs., and even more. In another place, when referring to rolling mills, the consumption of coal per indicated horse-power was given as 7 to 8 lbs. It would be very interesting to know how these figures have been arrived at, especially those giving the horse-power upon the work turned out. With regard to the figures (7 to 8 lbs.) given as the consumption of coal per indicated horse-power per hour, they seemed abnormally high. He presumed that the indicated horse-power had been calculated from full work diagrams, and from an assumed uniform piston speed for the minute of time. That, however, was not the case

with reversing engines. With regard to the figures given as the horse-power upon the work done, or rather turned out, he was well aware of great injustice being done to rolling and other engines in connection with rolling mills in this respect, owing to the irregular system of working. It was the system of working that was mostly at fault. The stokers at the boilers never knew when the work was coming on, and so they dared not bank the fires, or even slack firing, and the consequence was that much fuel was burnt to no purpose. With the same system prevailing, it was difficult to see how matters could be any better with regard to firing the boilers supplying steam for the engines of the electric generators.

The author characterised all the engines in connection with rolling mills as uneconomical, using low-pressure steam, with little or no cut-off. But he (Mr. Richards) failed to see any reason whatever why all the engines in a rolling mill, with the exception of the reversing engines, should not be economical as regards steam consumption. There was nothing in the way of having early cut-off, or of having compound, or triple expansions, nor of having steam of 150 lbs. per square inch, or any other desired pressure, if suitable boilers were put up. Nor was there need to have long lines of steam pipes to connect the auxiliary engines with the main boilers, as managers have of late years been fully alive to the advantages of utilising the waste heat of the heating furnaces for generating steam, and making direct steam-pipe connections between the furnace boilers and the auxiliary engines. Under the circumstances detailed, it was again difficult to see the advantage of electric motive power over that of steam direct.

Most engines such as are tabulated on page 256 of the paper had to do a great variety of work in which the power absorbed varied between very wide limits, and hence it was necessary to provide power for the heaviest, and often more or less unknown work, and if the engine was provided with an automatic variable cut-off, nothing could be much amiss. The employment of electric motors for doing the same class of work would be under similar circumstances, that was a punching machine, or a straightening press would be dealing with a light section at one time, and a very heavy one at another, so that it appeared that to take an electric motor to measure the power absorbed at any one time, would be

of little value for determining what the permanent motor should be. With regard to the application of electric motive power for driving reversing rolling mills, the author spoke with what he (Mr. Richards) considered proper reserve. Being well acquainted with the reversing rolling mill engine from the time of its introduction, he was of opinion that there was no other engine, not even the marine engine when working under the most trying circumstances, that could be compared with it as regarded the work it had to do and the manner it had to be driven. Owing to the long stroke of five feet, which was very commonly adopted, the piston speed ran up to 1000, and even 1200 feet at times, and it had to be reversed from 12 to 15 times in about every $2\frac{1}{2}$ minutes. With an electric motor running in the manner just described, there would, he thought, be some considerable difficulty in governing the electric generator, with the energy taken from it in great gulps at one instant, and none in the next. The effect upon the motor driving the rolls was also difficult to foretell. There was, however, no doubt that the reversing rolling mill engine was susceptible of improvements as regarded economy in the consumption of steam. There was, too, room for great improvements in the mode of generating steam for it. He had long thought that the cylindrical multitubular marine boiler, or any other boiler in which there would be a maximum concentration of evaporative power, with a minimum of occupied space, should be adopted. Such boilers would admit of being placed close to the main engines for which they were to supply steam, and the great loss of heat, not only from condensation in the present long lengths of steam-pipe connections, but also that from conduction from the external flues of the Lancashire boilers, through the brickwork surrounding them. Also the heat absorbed in the brickwork itself, and in the great weight of water contained in a large battery of such boilers, which for the most part was thrown away when they were let out at the end of the week, and had to be replaced at the time of relighting, would be saved.

Mr. B. H. THWAITE stated that some months ago he was requested to design a small iron and steel works for abroad; in a position where the utilisation of the fullest possible measure of

heat in the fuel available, was of the highest importance. A careful study of all the conditions of manufacture, and of the resources that modern science had rendered available, led him to decide on the following briefly described scheme of producing heat for fusion purposes, and for the production of power and the transmission and application dynamically of such power to the various mechanically and widely separated parts of the plant.

The scheme might be described as follows:—

1. The production of power, in three phases.
 - a. The conversion of the solid fuel in special generators (automatically controlled and fed) into a gaseous condition.
 - b. The recovery of the nitrogenous constituents of such fuel in the form of commercial ammoniac sulphate.
 - c. The storage of such gaseous fuel in containers, and its utilisation for furnace work, and for the production of power by an internal combustion or thermo-dynamic motor, or gas engine.

N.B.—Such plant should be centralised, so that it would be convenient for the delivery of the fuel, and be centrally placed for distributing its gaseous production, to various parts of the work, and be sufficiently removed as to prevent the incursion of iron or slag dust suspended in the atmosphere.

2. The transformation of the thermo-dynamic into dynamo-electric power. This was intended to be effected by electric machines actuated by the gas motors.

3. The transmission of such dynamo electric or electro-motive force (E.M.F.) to the different mechanical elements of the plant by means of underground or overhead well-insulated conductors.

4. The transfer of such power to the machines themselves. This was effected by electric motors placed either directly in connection with the machine, the armature of which formed the driving shaft, or the power is transmitted by belting from a pulley on the armature shaft to a pulley on the driving shaft of the machine.

In the scheme all the machines were intended to have separate electro-motors, and even the hammers were to be worked by powerful magnets with same power agency. The rolling mills were to be equipped with a powerful electric motor fixed on the same bedplate. All the cranes, both derrick, jib, central, travelling, overhead, and loco, had to have their own respective electric motors. The cold and

hot saws, the shears, the skull-breaker, the ladle carriage, the trollies, the rotary fans, were all to be equipped with their special motors and regulating switches. The ores, pig iron, limestone, fuel, and finished products, were to be transmitted from one part of the works to the other by electric locomotives. In the machine shops, the punch and shears, the portable and stationary drills, the lathes, grinding wheels, planing, boring, and slotting machines were each to be electrically actuated by separate motors.

By the scheme briefly described, it was calculated that an actual equivalent energy of one horse-power per hour could be directly applied in hoisting, propelling, conveying, and actuating the whole of the mechanical elements, including pumping, with an expenditure of only one and a half pounds of coal.

The loss of dynamic power in the electric conversion and transmission in any iron and steel works, need not exceed one-fifth of the initial available power, so that, given the development of the one brake horse-power, by the expenditure of one pound of gas in a gas motor cylinder, and one-fifth of this being added for losses of transformation and transmission as indicated, it would be seen that there was actually a margin for reduction on the $1\frac{1}{2}$ lbs. estimated. Comparing the present system of generating and transmitting power by steam boilers, steam pipes, and steam engines with the system of gas generators, gas motors, electric machines, and electric conductors and motors, it would be realised, on examination, that many of the attendant disadvantages of the first-named system would be either avoided or reduced. Some of these disadvantages might be enumerated as follows:—

a. Generally in iron and steel works the steam engines were of an inferior design, and were exceedingly wasteful in fuel.

If the efficiency of these smaller steam motors was examined, it would be found that it was very low, at least 6 lbs. of fuel being absorbed for one actual horse-power used applied for one hour, and this independently of the losses in the generation of steam and in the transmission of the steam power by exposed steam pipes.

b. As iron and steel works generally consisted of draughty open sheds, or covered spaces, open at the gable ends and sides, the pipes for conveying the steam power were necessarily exposed to severe

cooling conditions and changes of temperature, so that both leakage and condensation were associated evils.

c. Finely divided iron and slag particles floating in the atmosphere of iron and steel works, especially in the rolling and forging department, were productive of much deterioration of steam-engine machinery and its efficiency.

The metallic and slag particles fall on the moving and frictional parts, and wear them away—it was a rare sight to see a perfect steam-tight gland in an iron works steam engine.

d. The steam engines, large and small, scattered throughout the works, exposed to the draughty and cold influences, could not be expected to give the same efficiency as the well looked after and high-class textile mill engine in its beautifully kept house.

e. The difficulty of starting the engines, through condensation of steam, was an excuse for uninterrupted light load and wasteful running of the machines, so that much wasted energy was associated under this head.

f. In the present repair or machine shops, the main line and much of the counter shafting was constantly in motion, whether the machines or tools were working or not.

g. The present system of scattered small steam engines was prejudicial to good and economical work, and it would not compare in economy with the central system of a large power plant equal to the aggregate of the smaller engines.

h. If steam engines were not used, a long line of shafting was employed, and the waste of power by this means of transmission, whether by belt or toothed transmission gears, was most serious.

Considering the enumerated disadvantages to ascertain if the proposed central electric system will remove or modify them, he pointed out that—

a. The high-class steam or gas motor plant, erected in a central station, would at once lower the cost of fuel by fully one-third. It was well known that one indicated horse-power could be developed in gas motors with generated gas fuel, with an expenditure of less than 1 lb. of coal.

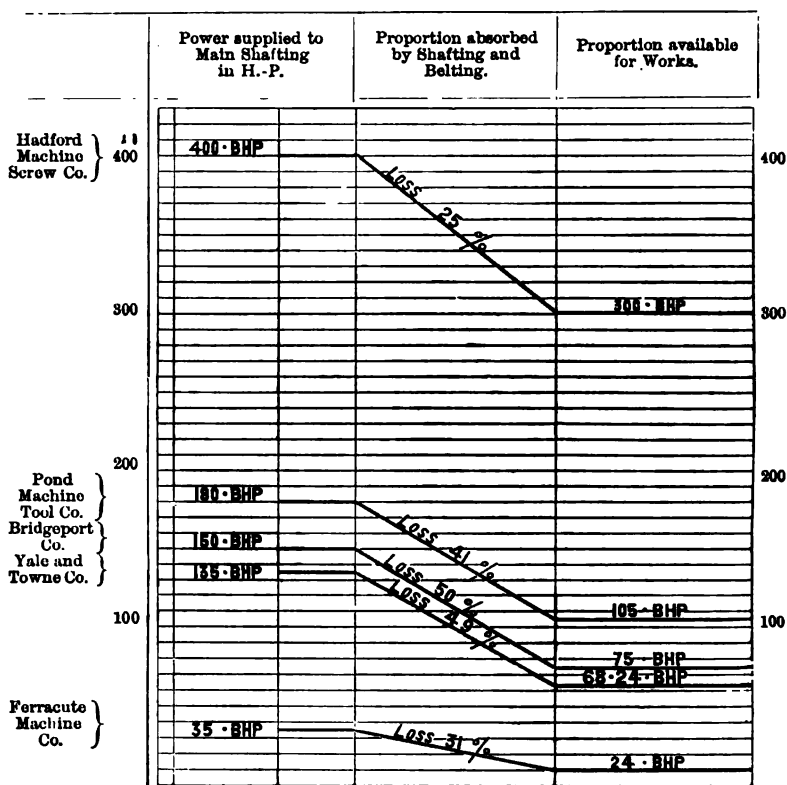
b. The transmission of the electric energy by well-insulated electric conductors, would not be affected by changes of atmos-

pheric temperature of the open and draughty sheds, and between the electric machines and the electric motor the loss of energy would be very fractional.

c. The central power station would not be exposed to floating

Graphic Diagram showing the Absorption of Power by Belting and Shafting.

BASED ON DYNAMOMETRIC INVESTIGATION.



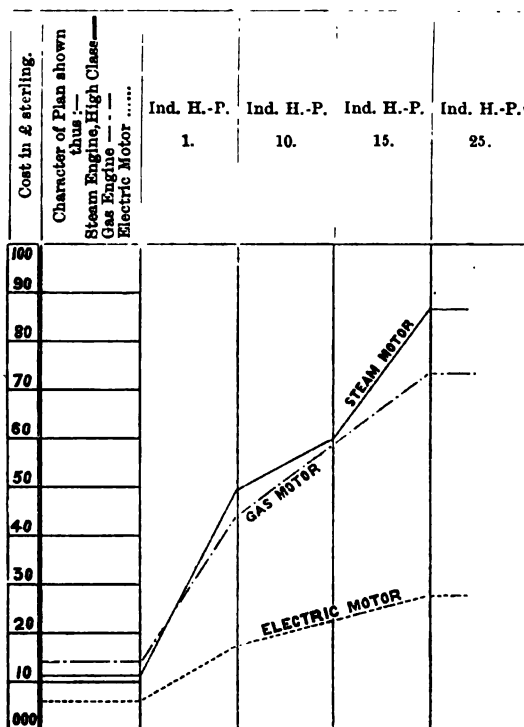
metallic and slag particles. The electric motors could be completely boxed in, so that they were not affected by dampness or by the iron or slag dust deposits.

d. and e. There was only one power generating station. Each electric motor could be thoroughly guarded, and when not required

in action, it could be instantly switched off or be restarted as requirements demanded. There was no need for free and wasteful running.

f. Each tool in the repair, turning, fitting, or other machine shop was actuated by its own motor, and could be switched on or off instantan. There was no need for the main and counter shaft-

Diagram showing respective Cost of Maintenance, Interest, Amortisation, and Repairs of three forms of Motor Installation.



ing to be wearing its bearings away by free and costly running. Reference to the accompanying diagrams would elucidate the loss of power in transmission of power by belting.

Besides the striking advantages of the scheme set forth, the system enabled electric lighting of a well-distributed character to be obtained at a trivial addition to current cost. Electric energy

could, with a little ingenuity, be applied for special and local purposes and conditions, much more conveniently than any other system.

The Oerlikon Machine Company of Switzerland, as well as other continental firms; the Electric Construction Company, Wolverhampton, Messrs. Mather & Platt, Oldham, had introduced numerous applications of electro-motive force. In the United States, many of the machines in daily use in iron and steel works were actuated electrically. The Carnegie Works, the Wrought Iron Bridge Company, the Cambrian Iron Company, the Bucyrus Steam Shovel Company, the Pencoyd Iron Works in the United States, were utilising this economical and efficient form of transmitting power.

Mr. Selby-Bigge's practical contribution was very opportune, and should tend to the popularisation of electrical applications in iron and steel works. The paper called for very few remarks beyond those of a congratulatory nature. He was glad to notice that stress was laid on the loss occasioned by condensation in steam-pipe transmission. The absence of dynamometric tests in British iron and steel works was to be deplored. In the United States this practicable method of testing the power absorbed by different machines had become common, and the information so far gathered was in the highest degree valuable and instructive. He would strongly recommend engineers to peruse Flather's work on the dynamometer, the information given being extremely valuable and practical. The thanks of metallurgists were due to the progressive firm of Dorman, Long & Company, Limited, for their pioneer work in electrical power applications in steel works in this country. Their obtained results were alone an eloquent testimony in favour of electric power transmission.

Obviously the best method of producing power for intermittent work, when a storage of power was required, was to use a *gas engine and gas-holder plant*; in the latter a large accumulation of power could be held in reserve, ready for momentary use, and without such storage involving any loss. This could not be said of any other system of power storage.

By means of a special switch-board and a multiplicity of motors, as the load was reduced, part of the gas motors might also be

automatically cut off as well as the gaseous fuel plant generating the gas that fed them. The suggestion for comparing the daily coal consumption per electrical horse-power absorbed was an admirable one and would conduce to the highest economy. The characteristic elasticity of the magnetic field of an electric motor was of the utmost value, and in no instance more than in the application of electric motors for driving a train of rolls, and this feature would probably be the means of preventing many disastrous and sudden strains that would be fatal with present methods. The author did not give any reason why the heavier rolls should not be electrically driven. He might have obtained useful information on the advantages of electric methods of driving workshop tools from the Electric Construction Company of Wolverhampton, who were on a large scale the pioneers in this country in the use of electric transmission of power for actuating workshop engineering tools.

METHODS OF PREPARING POLISHED SURFACES OF IRON AND STEEL FOR MICROSCOPIC EXAMINATION.

By J. E. STEAD, MIDDLESBROUGH.

INTRODUCTION.

PROFESSOR MARTENS, in his most admirable paper on the "Micro-structure of Ingot Iron in Cast Ingots," read before the Chicago meeting of the International Engineering Congress last year, referring to the application of the microscope to metallography, says: "Much diligent and patient labour will be required of many investigators, before microscopic metallography can be raised to the same practical level that chemistry now occupies. That this plane will be reached no one can doubt who has himself carried on these researches, or ever has had the opportunity to study a good collection of metal sections. As the complement of chemical analysis and mechanical tests, microscopy will afford us a deep insight into the constitution of the metal, and serve particularly to render the results of chemical analysis more intelligible."

Mr. F. Osmond, in his paper to the same Congress on "Microscopic Metallography," after referring to the microscopic work done by Dr. Sorby in this country, by Professors Wedding and Martens in Germany, by Messrs. Lynwood Garrison and Dudley in America, and by Mr. Barba at Le Creusot, and Messrs. Osmond and Werth in France, points out that "this interesting study is cultivated in the principal metallurgical countries. Starting from scientific laboratories, it is extending more and more into industrial laboratories, where it will probably become an indispensable auxiliary to chemical analysis and physical tests."

Albert Sauveur of South Chicago, in his paper on the "Micro-structure of Steel," although not venturing on any dogmatic deductions, states, however, that "already in the present state of our knowledge, we get much useful information from the microscopic examination of steel, especially when it includes the measurement of the grain." Such a method throws much light

on the way a certain steel is affected by a certain heat treatment. It shows within limits what maximum finishing temperature a steel of given composition will stand without assuming an objectionable crystalline structure, but above all it tells us a great deal about the past heat treatment of the metal.

Professor Arnold of Sheffield, in his remarks on the first report of the Alloys Research Committee presented to the Institute of Mechanical Engineers, recommends that "the examination of the steel should comprise its chemical composition, its mechanical properties under varying conditions whether annealed or un-annealed or hardened, its microscopic features, and its characteristics in respect of recalescence."

Now with the evidence before us, and the scientific researches of Dr. Sorby, Professors Martens and Arnold, Mr. Osmond and others, together with the direct evidence of Albert Sauveur of the practical usefulness of microscopic metallography, it is evidently time that this particular branch of research should not be neglected, and that in our works, and all metallurgical laboratories, the microscope should hold a prominent if not a premier position.

It was this conviction which led me to follow up this most interesting branch of study, and it must be confessed that without doubt it has been of assistance to me in solving some mysteries which neither chemical analysis or mechanical tests unaided could unravel. It is not my object in this communication to discuss the practical value of the microscope to the metallurgist, but to give, firstly, the various methods employed for the preparation of polished specimens of the metal requiring examination by those gentlemen who have made it their special study, and in this endeavour I must acknowledge with gratitude the readily given assistance of Dr. Sorby, Professor Martens, Professor Arnold, and Mr. Osmond (all of whom have sent me, for the benefit of the members of this Institute, exact and detailed descriptions of the methods employed by them in their laboratories), and, secondly, the result of my own endeavours.

The first method to be described is that of Dr. Sorby of Sheffield, which naturally deserves priority, as it was the first published, I believe, in the English language.

PART I.

Dr. H. C. SORBY'S METHOD.*

"In the majority of cases slices about one-tenth of an inch in thickness were cut in the required direction by a circular saw, and further reduced in thickness by filing or grinding until sufficiently thin not to make the final preparation heavy or clumsy. One side was then fixed with hard Canada balsam to the glass, on which it was finally kept, and the upper surface made as flat as possible by rubbing on emery-paper placed on a sheet of plate-glass, using in the first case somewhat coarse, and finally, the smoothest paper employed in preparing steel plates for engraving. It was, however, found that in many cases no good results could be obtained by polishing directly after using the fine emery-paper, because the surface was so much modified by the scratching; this exterior surface was, therefore, ground off by using fine-grained water-of-Ayr stone and water, until all trace of the scratches was removed. It was then polished on wet cloth stretched flat on a piece of wood, using in the first place the finest grained crocis, and lastly, the very best and finest washed rouge, so as to obtain a beautiful polish, almost or altogether free from even microscopic scratches, without any of such surface disturbance as is caused by a forced polish. This latter usually looks far better, because the minute cavities and other irregularities are hidden. In some cases the constituents are of such very different hardness that they are worn down unequally. Sometimes this is an advantage, since it serves to show the difference in hardness. For some purposes, however, it is very desirable to have all the constituents cut through on precisely the same level, and the surface of the hard portions flat and not rounded at the edges. This may be accomplished by polishing *dry* with rouge on a piece of parchment laid over a sheet of plate glass."

Dr. Sorby has quite recently informed me that some of his very best preparations were polished *dry* on parchment with

* *Journal of the Iron and Steel Institute*, No. I. 1887, p. 255.

rouge and *never acted on by acid*. This plan was adopted towards the end of his work, and possibly if he had to do much more he would employ this method more extensively. "Some of the specimens thus prepared were splendid, and whilst some of the constituents were *bright* and *metallic*, others were a *deep blue*. For some sorts of specimens this method is most excellent, and it is easy to leave off polishing when the structure is brought out to perfection. Cast iron and some steels come out splendidly."

MR. OSMOND'S METHOD.*

"The samples of steel or iron are either cut in a lathe, or by filing in a vice, or by other methods according to circumstances. It is of no importance which method is used, provided the sample is not mechanically distorted and is cut cold. Instead of cementing the specimen to any support, it is simply held by the fingers and is rubbed backwards and forward on the grinding or polishing surfaces.

"1. Rub down with a rough file, if that is necessary, and finish with fine file.

"2. Polish on emery-paper. The emery-paper is placed upon a piece of glass, upon which it is held in position with the left hand, the sample being rubbed up and down with the right. As a rule, four papers of graduated and increasing fineness are used.

(1.) Over paper marked 0, to remove file marks.

(2.) Over paper marked 02, 100 times backwards and forward.

(3.) Over paper marked 04, 100 times backwards and forward.

(4.) Over paper marked 06, 500 times backwards and forward.

"3. Finish on rouge. After leaving the emery-papers the sample is further polished with English gold rouge, which is spread on a sheet of parchment stretched over a small piece of oak. A little water is mixed with the rouge, and the sample

* Specially communicated.

is rubbed backwards and forward at least 500 times. It is then washed and dried with a linen cloth."

Sometimes a specimen is rouge-polished in a Fuess machine (which is also used by Professor Martens), the use of which saves a little time. This machine Mr. Osmond describes with the following sketch (Fig. 1):—

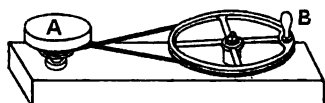


FIG. 1.

"A. is a metal platform on which a piece of cloth is put. On this cloth water is placed, and a little rouge. The handle B. is turned while the sample is held in the left hand.

"By proceeding as above directed, results will be obtained sufficient for industrial assays, and for judging of the thermal treatment of the samples." It does not matter at all if there are a few scratches visible. It is most necessary to have good emery-papers. Mr. Osmond had some trouble in that direction. The papers which he bought some years ago were suitable, but when more were wanted to renew his impoverished stock, no more of the same quality could be obtained, and consequently he could not get good results, and now is obliged to make papers himself with emery powders, which he also prepares. "This preliminary work is wearisome, but one is well repaid by the consequent easiness in polishing. When the finest emery-paper is what it ought to be, the rouge has not a great amount of work to do to give a perfect polish." The samples polished are never larger than $\frac{1}{2}$ inch by $\frac{1}{2}$ inch. If a larger surface than this is required it is necessary to cut it in pieces and polish them separately.

. PROFESSOR ARNOLD'S METHOD.*

Professor Arnold has kindly communicated the method he uses which he describes as follows:—

"The sections employed are $\frac{1}{2}$ inch in diameter by $\frac{1}{16}$ inch thick. Before leaving the machine-shop they are finished with a dead smooth file, the file marks are removed on a piece of the finest emery-cloth, tightly stretched on a hard wood board. The remain-

* Specially communicated.

ing operations are carried out on materials stretched by means of taper rings on machined cast-iron blocks of the size and shape shown in Fig. 2.

"On No. 1 block is the finest emery-cloth from which the coarse emery has been removed by rubbing first with a marble slab, and, secondly, with a piece of smooth hard steel about 1 inch diameter by $\frac{1}{2}$ inch thick. On No. 2 block is stretched thick black unribbed cloth, charged with oil, and the finest emery knife polish. On No. 3 block is a piece of finest wash leather slightly charged, dry, with the best jeweller's rouge. The average times occupied in each stage are as follows:—On emery-cloth five minutes and on Nos. 1, 2, and 3 blocks about ten minutes each."

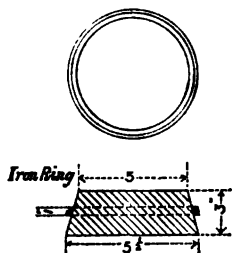


FIG. 2.

The plan adopted of rubbing off the coarser grains of emery from the commercial papers used is an excellent one, and possibly does away with the necessity of personally making specially fine papers. The circular blocks on which the emery-cloth, &c., are stretched, are very simple and effective.

PROFESSOR MARTENS' METHOD.*

"1. The samples are cut with a saw or file into slabs of as nearly as possible a thickness of from 1 to 2 mm. Brittle iron (spiegel-eisen) is split by a blow. Samples should always be taken perpendicular and parallel to the "Hauptrichtungen" (literally, chief directions) of the piece to be examined.

"2. The little plates (in some cases in large number and then arranged in a ring) are cemented to a level slab (of glass or metal) with a cement made of beeswax and resin (about 1 to 1), and to do this both the slab and the little plates are warmed until the cement melts. For polishing I very frequently prefer to take the little plates singly. The number may, however, be increased if one takes particular care that the rubbing surfaces (the surface of the polishing slab and the surfaces of the specimens being rubbed) remain level.

* Specially communicated.

"3. The surfaces to be rubbed (the ring of surfaces as described under 2) I then turn down in a lathe, so that all the little plates are level. With very hard specimens this must be done by grinding. For grinding and for 'fine grinding' I used emery (corundum), pounded quartz sand, oilstone (Mississippi stone, or oilstone powder, such as opticians use for grinding lenses). For polishing I use very fine quartz sand, oilstone, polishing rouge (both hard and soft). Grinding and polishing powders must be levigated most carefully and accurately according to time if one wishes to produce proper work.

"As beds (*grinding* plates) I use glass or metal plates (cast iron, copper, lead); as *polishing* beds I use plates of glass or pitch, and but seldom soft ones, such as leather, indiarubber, &c. Pitch plates are made from *pure* soft pitch, with a little resin added, by pouring the melted mixture out upon glass plates. In polishing, the chief thing is cleanly tidy work carried out in systematic sequence. The kind of 'bed' of grinding and of polishing powder must be selected according to the softness of metal to be handled. Experience soon teaches one to hit on the right thing.

"4. The time needed to produce a specimen is entirely dependent upon circumstances and experience. At first it takes days to obtain an imperfect result; afterwards it is possible to do in a few hours what formerly took weeks. Steel specimens of about 1 square centimetre surface, when from ten to twenty are done at once, can eventually be easily finished off in one day; with special arrangements even still more."

With regard to the washing process, Dr. Martens in his paper* describing the methods used at the "Versuchsanstalt," recommends that each operator should himself prepare the powders, and the very finest powder when obtained should be valued as a treasure. The plan adopted in its preparation is as follows:—

"Pear-shaped glass vessels, some of 2.5 litres and some of $\frac{1}{2}$ litre contents are used, and in them the grinding powders are shaken up with water. The coarse grains settle quicker and collect at the pointed bottom of the flask. The material is divided into grades of fineness according to the time required

* *Die Mikroskopische Untersuchung der Metalle. Vortrag des Professors Marten gehalten in der Versammlung des Vereins für Eisenbahnkunde am 12 April 1892.*

to settle; at the end of each time limit the water and suspended matter is syphoned off into a fresh flask, and allowed to settle there for so many minutes, the suspended matter again syphoned, and so on. By a systematic grading in this manner is obtained material of two, three, or more sizes of particles. For the finer grades is used $\frac{1}{2}$ litre flasks, and the powder is suspended in alcohol or ether."

In the same paper Dr. Martens gives exact and detailed descriptions of his methods of etching, examination, and photographing of the polished specimens. The following remarks on the further treatment of the polished specimens are most important and demand recognition:—

"When the section is polished it must be separated from its holder, and from the cement that adheres to it. The latter is first done mechanically, and finally by treating with alcohol and ether. The section is considered clean when, on removing from the ether, and allowing the adhering ether to evaporate, no rim remains on the polished surface. If this cleansing is not properly done, then, on subsequent warming of the section (for tempering or fastening to the 'object holder'), the residual cement wells up out of the interstices, and forms coloured puffed up ridges to the pores. These rims sometimes produce very deceptive appearances under the microscope.

"Surfaces polished in soft beds, on account of the varying hardness of the constituents of the section, show the 'joinings,' *i.e.*, the structure of the preparation, more or less clearly, and the coarser structures may be examined under low magnifying powers in this condition, but in order to obtain an insight into the finer structures the surfaces must be polished on hard polishing beds (pitch beds). The polished surfaces may be then etched or coloured to bring the components into view. Surfaces polished in soft beds also become usually more defined when etched or coloured."

Professor Martens informs me that R. Fuess of Steglitz is the manufacturer of small hand-machines for polishing and preparing samples of iron and steel, and that Max Hasse & Co. of Berlin are the makers of larger machines. Both classes of machines are similar in principle and are in reality lathes, and the various grinding-discs are fixed or screwed on to the poppet-head.

In the small hand-machine (Fig. 3), discs of metal, &c., on which the grinding powder and water are placed, are caused to revolve rapidly by turning a handle at the left, the sample holder carrying the specimen being gently pressed against the moving wheel with the right hand. This machine seems to be a valuable and useful instrument.

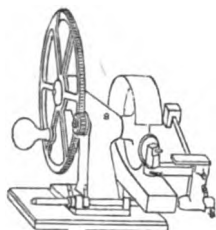


FIG. 3.

In the larger power machine of Max Hasse & Co., the grinding surfaces, consisting of properly prepared metal chucks carrying grinding rings of iron, copper, hard lead, soft lead, &c., are truly turned and fitted, and are placed as required on the large face plate of the lathe. The holder of the specimens is carried on a specially arranged slide rest, which has motion given to it by a pulley and cord in communication with the shafting overhead. The holder is a circular metal plate upon which a large number of specimens may be cemented. It is caused to revolve and to move backwards and forward across the face of the grinding rings, the pressure or feed being applied by turning a screw by hand on the slide rest. It is quite clear that with both machines the grinding can be done either wet or dry; they are, however, better adapted for wet grinding, and in order to prevent the water and powder from flying off, the discs are provided with guards. Where much work has to be done, and engine power is available, this machine seems to meet every requirement.

PART II.

It is most probable that if, about two years ago, we had been in possession of the information just given, we should not have directed attention to the designing of special apparatus, as it is evident that by the very simple means described by Mr. Osmond and by Professor Arnold, samples of iron and steel can be polished in a reasonably short time. Not, however, knowing the details of the methods of these gentlemen soon enough, I had directed my atten-

tion to the construction of suitable simple apparatus, which I now proceed to describe, and which if not absolutely necessary will, I hope, save the would-be "Metal-mikroskopiker" some valuable time and muscular exertion.

I must acknowledge that, since receiving the communications from our Continental and English friends, I have been able to correct what was defective in the first designs, and I am sure these great authorities will pardon me when it is known that, in following up this subject in their footsteps, my hope and wish is the same as they have expressed—to encourage the pursuit of a branch of science which has it in such great promise of usefulness and knowledge.

SMALL POWER MACHINE.

The first machine to be described is similar to that used for making lenses, and the grinding is all done on wet surfaces. It is not a hand-machine, but is designed so that it can be readily

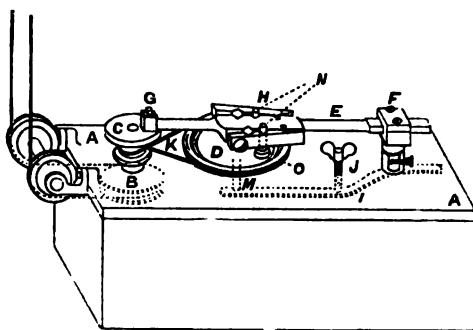


FIG. 4.

fixed in any part of a machine-shop, where a small driving-band can be attached.

A glance at the diagram (Fig. 4) will readily explain the construction.

The whole of the working parts are carried on the metal bed-plate A. The driving-pulley B is below the bed-plate. This

pulley is connected by a short shaft or spindle with the pulley C and the crank G above. The crank gives a rotary motion to the connecting-rod E, H, the end E of which travels through the swivelled guide F. At the centre H, on each side, is a strong clamp for holding the specimen carriers, which are opened or closed by turning the thumb-screws L. The circular grinding table D is caused to revolve slowly by means of the crossed pulley-band K, and is pressed upwards with a greater or less force by the strong steel spring I, which is regulated by turning the thumb-screw J. The specimen carriers N are made of brass, and are clamped one on each side of the arm H. The specimens are cemented upon the crowns O, which fit tightly on the carrier, but can be readily removed when required by the finger and thumb. The grinding and polishing powders are carried in small circular

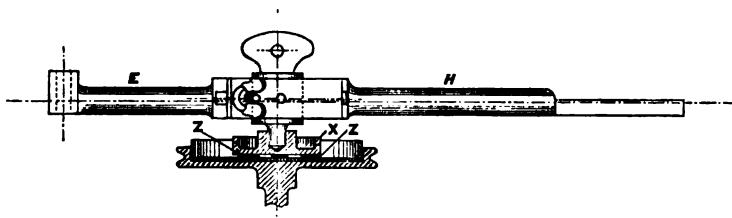


FIG. 5.

trays which fit into and turn with the table D. This machine was specially designed for polishing the ends of small wires or rods. For general work a strong pin is screwed into the centre of the connecting rod E, H, and this falls into the centre of a large crown-piece, upon which the specimens are cemented, as will be seen by Fig. 5. A still more simple modification has been made, in which the moving arm E, H has been replaced by another of the form shown in Fig. 6. Y, W is a slightly tapered brass plug, perfectly flat at the lower part, and, when the machine is at work, is kept secure in the carrier S by the set screw U. The plug Y, W is readily removed, and the sections of steel, eight or ten in number, are cemented on to its lower face.

The sections for preparation when soft enough are cut with a saw into slices about one-sixteenth of an inch in thickness, and

may be of any diameter, from one-half by half an inch to the diameter of the finest wire. When very hard, the pieces must be chipped or split off, and the flattest side be cemented to the crown O. The cement used may be very stiff Canada balsam—the cement recommended by Professor Martens, or, what I prefer, a very fusible solder.

When it is desired to examine small rods one-quarter to one-sixteenth inches in diameter, short lengths of the specimens may be clamped and polished up at one end, and after finishing may be fixed in a vice and the polished end cut off with a saw. The saws used can be purchased at any good ironmonger, and cost very little.

Rough Grinding.—In fixing the carriers into the clamps H, it

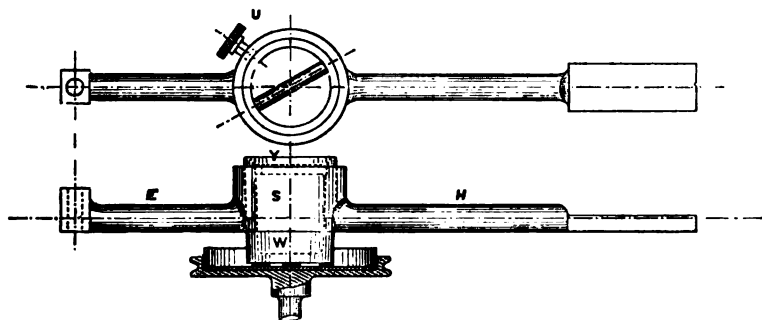


FIG. 6.

is necessary, first to screw down the spring I, so as to lower the table D to within half an inch of its lowest level, then to insert the carriers, one on each side, allowing the crowns to rest on the surface of the table; they are then clamped up, and are not again removed till the polishing is complete. The crowns, however, are removed from time to time to ascertain how the work proceeds.

The first tray carries an emery-wheel which is dropped into a recess on the table top, or, if preferred, the brass face of the tray may be covered with emery powder and water. In either case the machine is started, and the crank caused to move round at the rate of 200 to 300 revolutions per minute. More or less pressure as required can be applied by releasing the spring I. As soon as

the metal surfaces are ground quite flat, the crowns are washed, to remove the coarse grains of emery, and after removing the first tray the second is introduced, containing finer emery and water, and the grinding is continued till the scratches produced by the first grinding are removed.

The crowns are washed after each grinding. A third tray, containing still finer emery powder, is next used, and following that a tray carrying the finest emery.

Polishing.—1. The final stages consist of polishing on an agate plate with the finest rouge and water, or upon a pitch and resin plate, such as is used by Professor Martens. During this stage the apparatus should be enclosed with the cover provided, so as to exclude any possibility of dust or grit falling on the plate. Crowns carrying the specimens must be removed from time to time and examined by the aid of a double magnifying-glass, to ascertain if all the scratches have been removed, but after a little time and care experience will show how long a period is required to make a perfect polish. The samples will now be what Professor Martens calls flat polished.

2. If it is desired to develop the structure of a metal by polishing, the hard bed must be replaced by one of more pliant nature. Almost any yielding material will do, but I find the most serviceable to be smooth vulcanised and gritless indiarubber sheets. These are cut into discs and are placed at the bottom of the brass trays, and upon them is placed the rouge and water. After a little work the hard portions of the metal under treatment stand out in distinct relief. When the polishing is completed, the crowns are gently heated, the cement or soft solder softened, and the sections removed with a pair of forceps, and are then ready for further treatment.*

* These machines are made by Messrs. T. Carling & Sons, machinists, Middlesbrough, and can be obtained from Messrs. Griffin & Sons, 22 Garrick Street, London, and other dealers.

SMALL HAND-MACHINE.

The construction and working of this machine will be readily understood by consulting the sectional diagram.

By turning the handle F, rotary motion is produced in the flat circular table B, upon which the various grinding discs J are placed. The specimen holder C consists of a cylinder of brass, the lower extremity of which is closed, and has a projection about five-eighths in diameter, upon which the crown or cap E is placed. The specimens are cemented to the crown, several of which accompany each machine. By means of the frame I, and the fixed vertical shaft or pinion D, the holder can be moved completely round and away from the table B; but when the specimens are being ground, it is only moved so that the whole of the grinding surfaces are traversed, namely, from the centre to the outside of the discs.

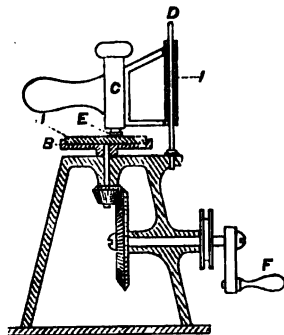


FIG. 7.

The grinding is done dry, and as a consequence the specimens are liable to get hot; but in order to cool the crowns the holder C is filled with water, and a plug is fitted at the top to prevent its escape.

The grinding discs consist of:—

1. A coarse emery wheel.
2. A fine flour emery wheel.
3. A plate glass disc upon which is glued fine emery-paper, or the plate itself may be coated for a foundation with a thin wash of gelatine and chrome alum, and after drying be washed with a thin layer of glue, upon which washed emery powder is dusted. When dry this forms an excellent grinding surface. A dozen plates may be coated in a few minutes.
4. A glass plate upon which is glued a piece of the finest emery-paper, or the glass itself may be coated with the finest washed emery powder in the manner described under 3.

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5. A slightly conical block, such as Professor Arnold uses, and which that gentleman suggested to me as suitable for this machine, upon which is stretched and kept in position by means of a metal ring, a sheet of smooth cloth. The cloth is laid on the surface of the block, and the ring is forced down into the position shown in the sketch. Upon this block is placed crocus powder.

6. This block is similar to the last, but instead of cloth, fine wash-leather is used. On this is placed the finest gold rouge.

The rough sawn sections are soldered to the crowns with a very fusible solder, or with pure tin.

The crowns are held over a spirit-lamp and a little chloride of zinc solution dropped upon the surface, and this is followed by a little powdered solder, which at once melts. The section is moistened with the zinc solution, and is dropped upon the melted solder. In a few seconds it will unite with the solder, when the crown is removed from the flame and the solder allowed to set. This operation takes less time to perform than to describe.

The crown is now slipped on the holder, and the coarse emery wheel is used to grind the specimen flat. As soon as this is accomplished the fine emery wheel is introduced, and the grinding is continued until the scratches from No. 1 wheel are effaced. By turning the crown at right angles after each grinding, the examination for scratches is very simple, as they will be seen to be at right angles to the marks produced by the grinding surface following.

The other discs follow in numerical order, when a perfect polish will be produced, and the sample will be ready for etching. I have done this with the crown attached and find it a great advantage, for if the etching should by chance be carried too far it is easy to slip it on to the machine and polish up once more. There are certain cases when this is not advisable, for when a long continued and deep etching is required, the crown itself is partially dissolved, and the copper from the brass is precipitated on the polished surface.

When it is desired to remove the specimen the crown is heated, the specimen being held with a pair of forceps. The moment the solder softens the crown drops off, leaving the sample ready for etching and examination.

POLISHING BY HAND.

When it is desired to polish very small sections by hand, such, for instance, as small pieces of wire, it is imperative to have appliances by means of which the surfaces are kept quite flat during the grinding. A special device to meet this necessity has been designed which is exceedingly simple, and consists of a plate of brass about $1\frac{1}{2}$ to 2 inches long and 1 inch wide, to the under side of which are fixed four projections on which small crowns carrying the specimens or caps are placed. To the upper side of the plate a knob of wood is firmly screwed. The following sketch (Fig. 8) will make the matter clear:—

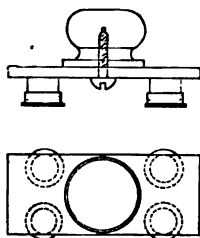


Fig. 8.

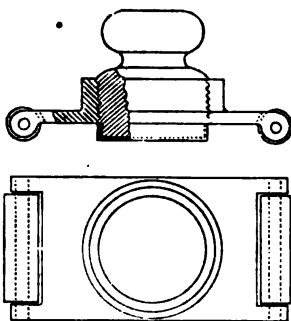


Fig. 9.

polishing may be effected on the surfaces described by Professor Martens, Dr. Sorby, Mr. Osmond, or by Professor Arnold. Further description is not necessary.

An increased size of holder with larger nipples and crowns can be employed for surfaces $\frac{1}{2}$ in. \times $\frac{1}{2}$ in. specimens, and four samples can be polished almost as easily as one.

For very large sections, say 1 inch to $1\frac{1}{2}$ inch square, a modified holder has been designed. This consists of a small carriage, the rollers of which are covered with indiarubber. The section is carried on an adjustable screwed holder in the centre, which is screwed up or down as required. The above sketch (Fig. 9) speaks for itself.

In using these holders it is preferable to use full size emery sheets glued upon each side of schoolboys' slates. These slates are ground perfectly flat, and make simple inexpensive beds. Instead of glueing sheets upon the slate, emery powder and water may be placed on it, and the grinding at once be commenced.

The fine grinding is done on finer emery, either wet or dry, and the polishing is done on either soft or hard beds. In the former case, pieces of cloth are cemented to the slate surfaces for the first polish, and this is covered with crocus powder damped with water. The polish is completed on dry chamois leather covered with best gold rouge.

If a flat surface is required, hard beds must be used. Nothing for this purpose can surpass Professor Martens' pitch beds. These can be prepared as directed by that gentleman, or by simply filling up one side of a schoolboy's slate with medium soft pitch, which is first melted in a ladle, and then poured into the previously heated and perfectly levelled slate. If any bubbles rise to the surface they are quickly removed by passing the flame of a large Bunsen burner over them. The surface will become mirror-like in appearance, perfectly smooth and flat. It should be covered up carefully to prevent dust falling upon it until it has become quite cold.

Water and the properly graded powders are placed on these slabs, and finally the best rouge and water are used on a slab kept specially for the finest work, and upon it the final polish is obtained.

PROCESS OF WASHING AND PREPARING THE EMERY POWDERS.

The graduating of the emery powders is effected by a similar process to that used by Professor Martens. To effect this a gallon or half gallon tin bottle is deprived of its bottom, and is then inverted and supported on the ring of a retort stand. A perforated cork, through which a brass tube passes, is inserted in the neck of the bottle (Fig. 10).

The upper part of the brass tube is soldered to a 3-inch very flat saucer. A suitable vessel is placed below to receive the water which flows from the vessel above.

For the intermediate grinding, flour emery may be graded. Half a pound of the powder is placed in a large porcelain mortar, and is mixed with sufficient water to make with it a thin paste. If it is not made into a paste at first it is liable to float on the water, in which case grading would be impossible. When the paste is properly made it is washed out into a large tin or other vessel, and one gallon of water is added. After thorough agitation, the mixture is poured into the separator, and the coarse powder allowed to settle. In five minutes the saucer A must be drawn down to just above the contracted part of the bottle C, and the water carrying the powder allowed to run into a vessel placed below for its reception. On standing, the fine powder settles to the bottom and is collected and dried. The coarse powder remaining in the separator is also collected.

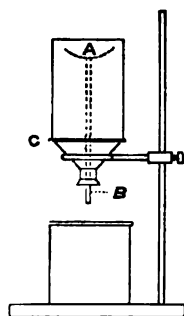


FIG. 10.

In preparing the finest material the best washed emery powder must be obtained, and after preparing it exactly in the manner described for flour emery it is introduced into the separator.

After waiting for a short time (fifteen minutes or more) sample drops of the liquid are drawn off from various depths below the surface with a small glass tube 1 mm. bore, and each drop is examined under the microscope, using a $\frac{1}{4}$ -inch objective. This examination does not occupy more than a few minutes, and need only be made once upon a portion of each parcel of powder purchased.

When it is found at what depth the grains are fine enough, the tube B is drawn down to that point, and the water with suspended powder is run into the vessel below. The tube is again raised, more water is added to the vessel till the quantity added equals what was withdrawn. The powder and water are now stirred up together, and the same process is repeated, omitting of course the microscopic examination.

When all the fine portions are in this way separated, the large bulk of liquid carrying the fine powder is allowed to stand till all is settled. The clear water is syphoned off, and the slurry is washed out into a porcelain dish, where the powder rapidly settles.

The water is decanted off as completely as possible, and the residual powder is dried in a water-bath, taking care to cover it up so as to prevent the entrance of any dust.

The coarser portion remaining in the separator is graded further into two classes. This is done by again mixing with water, and after allowing the heavier portions to subside the liquid above is run off.

All the powders must be kept in glass-stoppered bottles and properly labelled, so as to indicate the relative degrees of fineness.

In concluding this paper I must acknowledge with gratitude the valuable assistance of Professor Martens, of Mr. Osmond, of Dr. Sorby, and of Professor Arnold in communicating their methods of working for the benefit of the members of this Institute.

It is the hope not only of myself, but also, I am quite sure, of all these gentlemen, that by bringing together the various systems of working into one focus the study of metal-micrography may receive a stimulus, and that before long the united labours of many workers will greatly add to our knowledge of the complex constitution of iron and steel.

Those who wish to commence this study should read the papers on the subject read before the Chicago meeting last year, and as many as can be procured of the articles referred to by Mr. Osmond in the appendix to his paper.

This appendix, with additions, is here reproduced.

APPENDIX.

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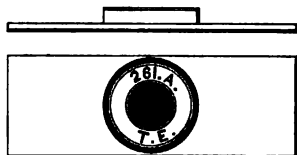
CORRESPONDENCE.

Professor J. O. ARNOLD stated that experiments he had made with the earliest form of Mr. Stead's polishing machine led him to believe that, with the proposed alterations, the improved hand machine would form a very useful adjunct to the apparatus of a steelworks laboratory: at the same time, he thought that for standard sections and for research work, where time was not of much moment, hand-prepared surfaces would be difficult to equal.

It was a matter of great importance to keep the blocks, when not in use, carefully covered up with bell-jars, because floating particles of fine, gritty dust produced the most disastrous effects on the excessively delicate surface of polished steel. He was much interested in the description of Professor Martens' pitch blocks for flat surfaces, as it was often useful to have a section without the slight microscopic roughness imparted by even the finest wash leather. He had always used, for this purpose, Dr. Sorby's parchment-coated plate-glass slab, but it was liable to produce scratches, unless the texture of the parchment was very even. It was often very profitable to examine two sections of the same steel, one etched, and the other unetched. With reference to deep etching, he had found it most misleading, as the lines of attack did not seem to be much connected with the structure, but rather to be determined by mechanical imperfections of preparation and other external causes, *e.g.*, finger-marks, which were fatal.

With a view to rendering the paper more complete, he ventured to describe his method for mounting and preserving the sections after etching. The plan found most convenient was as follows:—The pieces were mounted in brass cells, on 3-inch by 1-inch glass slips: the cells were prepared from rolled brass tubing, 1 inch outside and $\frac{7}{8}$ inch inside diameters; the tubing was placed in a lathe on a mandril, and the cells were cut off $\frac{1}{16}$ inch deep by means of a micrometer arrangement, and were finished on emery cloth. They were cemented to the slips with a solution of Canada balsam in chloroform, the latter being allowed to dry spontaneously, heat rendering the balsam some-

what brittle. The section was mounted in the centre of the cell, the cement being allowed to dry for a few hours in a desiccator before hermetically sealing the cell with a thin inch cover-glass, by means of balsam. Previous to this the sections were labelled with very thin cardboard rings, cut out with an instrument like a pair of medium inkbows, with only one blade. The inside diameter of the card rings was $\frac{1}{2}$ -inch full, the outside diameter, $\frac{7}{8}$ -inch bare. The circular label, thus just dropped into the annular space between the section and the cell, upon it being written the history of the steel. This arrangement was shown in the accompanying woodcut.



The labelling was best arranged by a small code: thus, in the illustration given, the indications were, steel, No.

261 annealed, transverse section, etched. The code used was as follows:—On the top of the cardboard ring O denoted ordinary, and referred to steel as it left the rolls or hammer. N was normal, and referred to the steel heated to 1000° and allowed to cool in air to remove any possible crystalline distortion effects. C was cast, and referred to ingots or castings in the condition they left the moulds. A was the process of annealing applied to steel castings. FA the process of annealing applied to files. OA (ore annealed) the process applied to malleable iron castings. T 400° C = steel tempered at 400° C. Similar contractions such as H, hardened; Hm., hammered; Rl., rolled; CRL., cold rolled, would suggest themselves. The code for the bottom of the ring ran thus: T.E., transverse etched; T.U., transverse unetched; L.E., longitudinal section etched, and L.U., longitudinal unetched. For the etching and benzole treatment glass baths 3 inches by 1 inch by $\frac{1}{2}$ inch deep were very convenient. The etching operation should be watched through a powerful hand-lens, and only experience and sometimes experiments could determine the proper extent to which it should be carried. In conclusion, he could only express his conviction that in thus bringing forward the question of the micro-structure of steel the author had done great service to those who were struggling to place the metallurgy of the alloys of iron on an accurate scientific basis.

Professor A. MARTENS pointed out that the small machine represented in Fig. 3 was not the Fuess hand-polishing machine used by him. That employed was more like that shown in Fig. 1, fitted for his own use with a swinging lever as shown in Fig. 4. The machine represented in Fig. 3 was a Fuess machine for cutting gems or crystals to particular axes, a process rarely necessary in metal-microscopy.

The machine made by Max Hasse & Co. was not suitable for polishing, but only for grinding large pieces or a large number of small pieces if required. In order to polish with that machine, it is necessary to have recourse to arrangements similar to those adopted by opticians, and sketched in Fig. 4.

Mr. F. OSMOND much appreciated Mr. Stead's excellent idea in collating the various methods of preparing polished surfaces adopted in the various investigations referring to the micro-structure of steel. He had often sought to explain results obtained in different ways and apparently not in accord, and he had usually found that each of them was accurate as far as it went, but that each of the two methods of preparation had only shown a different part of the question. As his own knowledge of the subject increased with time, he came to the conclusion that it was almost impossible to exhibit clearly at the same time all that it was of interest to show, and it would probably be necessary, in order to properly understand the readings, to make two, three, four, or five photographs of the same section in different stages of preparation. It was to be desired that each experimenter would publish the photographs of *typical metals* after the use of each powder, and indicate the time which was necessary to arrive at the result shown. Comparisons might be made in this way which would probably be useful to every one. Industries which were dependent upon such polishing process, and which usually employed empirical recipes formulated by long experience, would without doubt find advantage from that course. It was striking, when using the polishing process, to see how an operation so simple in appearance presented points which were unexplained, and which suggested abstruse scientific problems.

The ingenious little machines studied by Mr. Stead would doubtless render considerable service in accelerating and facili-

tating the work that was necessary, and in developing the taste for new branches of study, the scientific and practical importance of which appeared now to be generally admitted.

Mr. A. E. TUCKER had, during the last few years, made several microscopical examinations of steel and iron, and his methods of preparing samples was to grind down on a solid emery wheel. These could be readily purchased of varying fineness, were very uniform, cut very quickly, and lasted a long time. The advantages of a lathe, or better still, of a proper grinding and polishing machine, such as were largely used in the Birmingham district, were very considerable, the labour and time being reduced to a minimum. The polishing presented some distinct features from the method advocated by Mr. Stead, and consisted in using discs of various grades running at a high velocity. These discs were composed of an alloy of equal parts of lead and tin. They were comparatively hard. If it were desired to get a harder surface, it could of course be obtained by adding bismuth or antimony. The discs were about a foot in diameter, and were prepared by first cutting a face on them and then working emery powder of any suitable fineness into them. This was done by putting the emery on to the disc with a wet brush, and pressing it into the surface with a piece of flint while the disc was running. In that way excellent cutting faces were obtained, and by varying the fineness of the emery, and using rouge or putty powder on the last disc, any desired polish might be obtained. The process was known in the Birmingham district as lapping, and was largely used in the jewellery trade, where the highest possible polish was required. The facets for steel jewellery were prepared in this way. The master patterns were lapped on discs in the way described, and the resulting surface was so fine, that the steel stamped into the dies left them with the well-known beautiful surfaces, which might or might not be afterwards tinted by heating. He had by that method obtained perfect surfaces from the rough metal in two or three minutes, the respective laps taking about half a minute each.

The merit of the method depended on the high velocity at which the lap was running, say 10,000 feet per minute. At that speed the cutting was very rapid, and the work did not develop

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such heat as when the operation was more protracted, though of course it might be necessary to cool in water. As the available cutting surface was considerable, such discs, of which not more than three would be required, lasted a very long time. When rather large polished surfaces were required, it was desirable to bring the steel up to the discs by means of a guide, otherwise it was difficult to avoid cutting facets on the piece.

ON THE ANALYSIS OF STEEL.

BY HENRY KELWAY BAMBER, F.I.C.

FEELING somewhat dissatisfied with the ordinary methods of separating and determining the quantities of phosphorus and sulphur in steels, I set on foot some experiments with the view of arriving at some more satisfactory method, and in carrying out these investigations I obtained results far beyond my expectations; for by the method I adopted I found I obtained all the phosphorus, sulphur, and arsenic, as well as chromium, vanadium, and molybdenum, *when present*, by the first portion of the process entirely free from iron, and in combination with soda. Of course, when so obtained, their determination afterwards is a simple matter, and can be carried out by the several methods which each operator prefers. I started first with the fact that, under ordinary circumstances, when you have a solution containing several ingredients, the strongest acids will be combined with the strongest bases. I therefore dissolved the steels in diluted nitric acid, boiled until thoroughly dissolved and oxidised. I then added some *pure* sodium carbonate, taking care to leave the solution still acid. This was, of course, immediately converted chiefly into sodium nitrate, but also combined with the phosphoric and sulphuric acids present; the solution was evaporated to dryness and ignited; the residue, consisting chiefly of oxide of iron, was then powdered and treated with distilled water, containing some pure sodium carbonate, filtered and washed, when a bright colourless solution was obtained, except when chromium was present in the steel, when the solution was bright yellow, the colour varying with the quantity of chromium present.

If it is attempted to use distilled water free from the sodium carbonate, it will be found impossible to filter it, as the *finely divided* oxide of iron will pass through the best filter-paper. It is even then advisable to have two filter-papers, a smaller one inside a larger one, as the oxide of iron has a strong tendency to creep up and pass over the top of the filtrate.

By the use of this method in the ordinary analysis of steels for the Indian railways, I have in several cases found chromium present where it was not even suspected. In one case I had a piece of spring steel, which had been analysed elsewhere in the usual way, and chromium not being suspected, was not specially looked for, and therefore not found. It was in this case then found, that as the engineer would not allow more than 1 per cent. of carbon, it was difficult to obtain the required properties with this amount of carbon, and the manufacturer had been adding about 0·326 per cent. of chromium as a help. The result was that all these springs had stood the required tests and had been passed.

I find also that nearly all basic pig iron contains more or less chromium, and where chromium is present there is generally more or less vanadium or molybdenum. I find arsenic also present in nearly every sample of steel tested by this process, and of course if the phosphorus is precipitated by ammonium molybdate, more or less arsenic will be present in the precipitate and calculated as phosphorus. If the precipitation takes place at a temperature at which no arsenic is precipitated, it is only the phosphorus that is determined and there may be nearly as much arsenic present; and as it is believed to have the same effect on steel as phosphorus, the after-behaviour of the steel may be difficult to explain from the analysis. The discrepancies in the varied determinations of phosphorus in steel have been attributed to various causes; one person believing that the phosphoric acid became reduced to a lower oxide, he therefore boiled with successive portions of an oxidising agent, bromine. My opinion is that when phosphorus is once converted into phosphoric acid it is not likely, in the ordinary process of analysis, to be reduced to a lower oxide; but when evaporated to dryness with an acid to remove silica, especially in the absence of an alkali, it may be, and very likely is, dehydrated, and then not precipitable in the usual way by ammonium molybdate or ammonia magnesia mixture. If, however, it be boiled for some time with soda or ammonia, it gradually becomes reconverted into the ordinary phosphoric acid, and is then precipitable.

The analysis is carried out in the following manner:—200 grains of the steel in drillings are taken, to which is added 4

ounces of distilled water previously mixed with $2\frac{1}{2}$ ounces of *pure* nitric acid, specific gravity 1.42. When the violent action has ceased, it is boiled for some time until all action has ceased and the steel is completely dissolved. To this there is added an ounce of a 10 per cent. solution of *pure* sodium carbonate, boiled to remove carbonic acid, then evaporated to dryness, ignited in a platinum vessel at a dull red heat over a Bunsen burner. The red powder is then treated with another half ounce of the above 10 per cent. sodium carbonate solution, evaporated to dryness, then treated with hot distilled water containing about 0.5 per cent. pure sodium carbonate, filtered and washed carefully with the same.

If chromium be absent, the solution may be acidulated and evaporated to dryness to remove silica, and the analysis carried on by the processes preferred by the analyst. I generally precipitate the phosphorus as ammonia magnesia phosphate, which also takes all the arsenic down as ammonia magnesia arsenate, which can be weighed together, the residue being afterwards dissolved in diluted acid, and the arsenic separated and quantity determined and deducted from combined results.

Where time is an object, it is advisable to have separate solutions for the determination of the sulphur.

If chromium be present, it is advisable to add the magnesia mixture with a little extra ammonium chloride direct to the alkaline solution containing the phosphoric acid, &c., when the phosphorus and arsenic are separated without any trace of chromium, the precipitate redissolved and reprecipitated to obtain pure.

If the solution containing sodium chromate be acidulated by hydrochloric acid, some of the chromium will be reduced to oxide, and interfere with all the future processes of analysis.

I give now a few only of the close results obtained in duplicate analyses of steels in ordinary business.

Four steels, merely marked 1, 2, 3, 4, gave the following results:—

No. 1.	0.066 per cent.	and	0.066 per cent.	phosphorus and arsenic.
No. 2.	0.058	"	0.061	" " "
No. 3.	0.071	"	0.072	" " "
No. 4.	0.072	"	0.070	" " "

Two steel rails, marked 1 and 2:—

No. 1. 0·059 per cent. and 0·057 per cent. phosphorus and arsenic (arsenic 0·015 per cent.).

No. 2. 0·061 per cent., 0·061 per cent., and 0·060 per cent. phosphorus and arsenic (arsenic 0·016 per cent.).

Three steel rails, marked 1, 2, 3:—

No. 1. 0·036 per cent. and 0·038 per cent. phosphorus and arsenic.

No. 2. 0·046 " 0·048 " " "

No. 3. 0·047 " 0·044 " " "

Steel rail—seven determinations of the same rail for this paper:—Phosphorus only 0·029 per cent.; 0·029 per cent., 0·030 per cent., 0·031 per cent., 0·032 per cent., 0·030 per cent., 0·030 per cent.; in addition it contained 0·018 per cent. of arsenic.

If this had been all calculated as magnesium pyrophosphate, it would have shown an average of 0·041 per cent. phosphorus.

Now as to sulphur determinations, the following results in duplicate will suffice:—

Rails.

No. 1. 0·049 per cent. and 0·051 per cent. sulphur.

No. 2. 0·051 " 0·054 " "

No. 3. 0·051 " 0·049 " "

No. 4. 0·046 " 0·046 " "

No. 5. 0·057 " 0·057 " "

Steel Springs.

0·025, 0·025, and 0·024 per cent. sulphur.

I find that in chromium steels containing about 5 per cent. chromium, only about a third of the chromium is really dissolved in the steel, the remainder being probably in the form of ferro-chrome, as introduced into the steel. This may be the result of the difference of melting-point of the steel and the ferro-chrome.

CORRESPONDENCE.

Mr. F. HARBORD said he was much interested in reading Mr. Bamber's paper, and, assuming that results from his method were satisfactory, he thought it might be advantageously used in many cases. He therefore started an analysis of a sample of steel, following most carefully all the details given, with the object of seeing if the whole of the phosphorus were removed and passed into solution as described. After ignition in a platinum dish, and most careful washing of the oxide of iron, both by decantation and on the filter, with boiling water containing sodium carbonate, when the whole of the phosphorus should have been removed (the total washings amounting to 7 or 8 litres), he dissolved the residual oxide of iron in hydrochloric acid and examined it to see if it were free from phosphorus and arsenic. He then found it contained over 40 per cent. of the phosphorus that was originally present in the sample. Thinking that he might possibly have missed some point, such as igniting at too high or too low a temperature, he requested his colleague, Dr. Matthews, to independently analyse another sample. After ignition in a platinum dish, and extraction with water with most elaborate washing of the oxide of iron left, it was handed over to him (Mr. Harbord) for examination, when he found it also contained over 40 per cent. of the phosphorus and arsenic originally present. Thus any estimation of phosphorus by the method described would apparently give results 40 per cent. too low. It was regretted that Mr. Bamber did not give some analyses comparing his method with others in general use, as the results he gave simply showed that analyses made by the new method gave concordant results.

Mr. EDWARD RILEY, as an analytical chemist, judging from an experience of forty-five years, did not think the method a good one. He was, however, unwilling to be in any way prejudiced against it. He had therefore had some experiments made in his laboratory, and found that in operating on samples that had been analysed, only about half the quantity of the phosphorus and

sulphur was found in carrying out the analysis in the manner described by Mr. Bamber in his paper.

Mr. J. E. STEAD said that in considering methods of analysis several conditions must be accepted. 1st, The method must give the true amount of the element looked for. 2nd, It should not, by very slight irregularity in working it, be liable to give erroneous results. 3rd, It should be fairly practicable, and should not take too much time or attention to work it. The last condition was absolutely essential when the method had to be used in the laboratory of the manufacturer, for in such laboratories, in this country at least, the amount of dust and smoke, &c. floating about was excessive, and prolonged periods of evaporation and filtration generally meant analysis plus the dust, &c. which fell into the apparatus. With respect to the first condition, he must confess that although he had not really tried the method exactly on the lines laid down by Mr. Bamber, he saw no reason why correct results should not be obtained by it, and Mr. Bamber informed him that he had obtained true results, and as a proof said that on testing the same sample that they had tested, he obtained the same results as they (Pattinson and Stead) did when working by a different method of analysis. With regard to the second and third condition, he said that although Mr. Bamber and other analysts, who were working far from the dust-laden atmosphere, and far from the demand for rapid analyses in nearly all our iron works, might work it with advantage, for general work he was afraid the method was too tedious. For check work against other methods it was likely to be useful.

Mr. BAMBER, in reply to the discussion, stated that he would suggest that Mr. Harbord and Mr. E. Riley would not be likely to succeed with any new process of analysis, even if they wished to, by conducting the processes in the half-hearted way they appeared to have done. They most certainly did not so succeed at first, even with the process they generally employed, and he was certain that they, as well as others, found it sometimes failed in its results even after long practice. Mr. Harbord made one analysis, and obtained 60 per cent. of the phosphorus present in

the steel experimented on; and Mr. Edward Riley made some experiments, which he did not specify, and did not obtain more than 50 per cent. of the phosphorus present in the steel used. There was thus a discrepancy between the two chemists of 10 per cent. or more in their results; the process itself, therefore, could scarcely be the *only* cause of failure.

It was stated by Mr. Riley that, after forty-five years' experience as an analytical chemist, he did not think the process a good one; one would have thought that, with all those years' experience, he would have been able to give the reason why. Mr. Harbord seemed to think that elaborate washings are the chief points, but it was evident that if the first portions of the process were not done properly, all the washings, however elaborate, would be of no avail.

If the first parts of the process were properly conducted, *all* the phosphorus would exist as soluble sodium phosphate, and be easily and readily washed away from the iron. The author had recently made some analyses of steel, and measured the amount of liquid obtained at each step—after dissolving in dilute nitric acid, boiling, addition of sodium carbonate solution, again boiling, and when ready to pour into dishes to evaporate to dryness. The amounts did not exceed 4 oz. in either case, not quite 2000 grains; time, half an hour. These were evaporated to dryness and burned in about another hour and a half, boiled with sodium carbonate solution, and filtered and washed, resulting filtrates being only 6 oz., or not 3000 grains. These were then ready for determination of the phosphorus by any method desired by the operator within 3 to 3½ hours from commencement of the process; the results being—0.0854, 0.0826, and 0.0840 per cent. phosphorus and arsenic.

The author also made some analyses of metal from mixer from the North-Eastern Steelworks given to him by his friend Mr. Ridsdale, who found at the works 2.95 phosphorus and arsenic; the author found 2.976 and 2.968 phosphorus and arsenic. He had recently made another three analyses of the same, after separating the arsenic, with the following results:—2.716, 2.760, and 2.732 per cent. of phosphorus.

As the quantity of phosphorus was so great, only 10 grains of the metal was taken for each analysis. The metal was dissolved

in beakers with glass covers, and in half an hour were ready to pour into evaporating dishes. Volume, $1\frac{1}{2}$ oz. in each case. They were then evaporated to dryness, burned, and washed within two hours from commencement, and the filtrates measured not more than $3\frac{1}{2}$ oz. in either case. In washing, it was advisable to let each addition of water pass quite through the filter before adding more; by this means perfect washing was effected with much less liquid.

The author also analysed another sample from mixer, which Mr. Ridsdale found to contain 2.84; he found 2.823 per cent. of phosphorus and arsenic. One thing was necessary, that there should be no graphite left in the liquid before evaporation and burning, as that would and did reduce some of the phosphoric acid, and rendered the results too low. Mr. Harbord complained that the author did not test the process against others; he would see that he had done so. His paper, too, was intended to have been read last year, and was withdrawn only for the purpose of thoroughly testing its accuracy before publishing. The analyses against which it was repeatedly tested were those of Mr. Harbord and Mr. Edward Riley—in this way. Mr. William S. Rendel knew that the author was making experiments with the process, and, to enable him to test its accuracy, kindly had him supplied with duplicate pieces of some steels sent for analysis both to Mr. Harbord and Mr. Edward Riley, and when he had obtained his results, allowed him to compare them with those obtained by these two gentlemen. They would no doubt admit that it was therefore tested against two good analysts.

The author was perfectly satisfied of the accuracy of the process when properly conducted, which the results obtained by himself against Mr. Ridsdale, as given above, also show. It had also this great advantage, that whenever chromium or vanadium are present they must be detected without any special extra analysis. Both Mr. Harbord and Mr. Riley had had several samples of the spring steel mentioned, which contained 0.326 per cent. of chromium, and if they had been using this process they would inevitably have found it, and not included it in iron by difference.

Mr. Stead's objection to its applicability in works' laboratories, on account of the dust blowing about, was reasonable, but the author did not think in practice it would interfere, as all the

evaporations could be, and were, done by the author under glass covers; the work being done quicker, because if there was any spurting it was caught by the covers, and not lost.

Moreover, on several occasions when analysing the same sample of steel as Mr. Stead, he had always found his results come remarkably close to those obtained by Mr. Stead.

OBSERVATIONS ON THE
RELATIONS BETWEEN THE CHEMICAL CONSTITUTION
AND ULTIMATE STRENGTH OF STEEL

BY WILLIAM R. WEBSTER, PHILADELPHIA.

WHEN it was suggested that I should bring the results of my investigation before the Iron and Steel Institute, I hesitated about doing so until they were in a more complete form, including a full investigation of the effects of silicon and of the gases; but as this may require several years more work, I concluded to present them in their present form, in hopes that they will be fully criticised, and that there will be found enough new matter in them to induce others to take up or continue their work in this important line of investigation.

Over one thousand plates of basic Bessemer and basic open-hearth steel manufactured by the Pottstown Iron Company were tested and analysed in the course of this investigation. Through the courtesy of the Company, I am able to lay before the Institute the results of this work. The samples tested were all taken from the finished material, and the chemical determinations made on drillings from the broken test-pieces. These drillings were sent to the chemist without giving him the heat numbers or any information by which he could identify the material from which they were taken. In some cases part of the same drillings were sent to him under another laboratory number, in order to check the work.

Before attempting to investigate the effects of carbon, phosphorus, &c., on the ultimate strength of the steel, I had to find out how the ultimate strength was affected by the finishing temperature in rolling. This varies with thickness and width of plates, even when great care is taken to control the same. By rolling parts of the same heat into plates of different thicknesses the

following values were arrived at. Assuming a $\frac{3}{8}$ -inch plate under 70 inches wide to give normal results, we have corrections for size of plates shown in the following table:—

Plates.	Up to 70 in. Wide.	Over 70 in. Wide.
$\frac{3}{8}$ in. thick	- 2000 lbs.	- 1000 lbs.
$\frac{1}{2}$ " "	- 1750 "	- 750 "
$\frac{5}{8}$ " "	- 1500 "	- 500 "
$\frac{3}{4}$ " "	- 1250 "	- 250 "
$\frac{7}{8}$ " "	- 1000 "	\pm 0 "
1 " "	- 500 "	+ 500 "
$1\frac{1}{8}$ " "	\pm 0 "	+ 1000 "
$1\frac{1}{4}$ " "	+ 3000 "	+ 4000 "

On this point my results are not very satisfactory, but during the investigation the importance of controlling the temperature at which the plates were finished was brought out forcibly.

The tension test of each plate with its full analysis was written up on a small card, printed in the following manner, for convenience in dividing the tests under different headings:—

HEAT _____ TEST _____

MILL _____ PLATE _____

BLOOM _____ FINISHED _____

C. _____ S. _____ P. _____ Mn. _____

_____ E. L. _____ U. S. _____ ELONG. _____ % RED'N.

DIFFERENCE

Calculated Ultimate _____

Corrected for Size _____

REMARKS _____

My first table of estimated ultimate strengths was constructed by grouping the tests, according to chemical analysis, in various ways, and making a rough tabulated statement, from which the ultimate strengths were worked out and carefully compared with the actual results of the tension tests. From data thus obtained, one table after another was worked out, and by this method of "cutting and trying" I finally arrived at the results which I now present in Table I. I do not claim absolute accuracy, but my approximations have proved to be so close that the table and figures are now practical working data in current use at these works.

The indications from this investigation are that a $\frac{3}{8}$ -inch plate of pure iron, without carbon, sulphur, phosphorus, manganese, or silicon, if it could be obtained, would give an ultimate strength of about 34,750 lbs. per square inch. This is taken as a base, and to it is added the effect of each of the above elements on the ultimate strength, as explained below. The upper part of Table I. gives the ultimate strength due to pure iron, carbon, and phosphorus. The lower part gives the increase in ultimate strength due to manganese and to sulphur; the ultimate strength of Bessemer steel is found by adding these three values together; for example, a $\frac{3}{8}$ -inch plate with 0.15 carbon, 0.03 sulphur, 0.04 phosphorus, and 0.40 manganese would give—

	Lbs. per Square Inch.
Ultimate strength due to pure iron, 0.15 carbon, and 0.04 phosphorus	= 52,750
Increase in ultimate strength due to 0.40 manganese	= 8,600
" " " 0.03 sulphur	= 1,500
Estimated ultimate strength	= 62,850

For the ultimate strength of open-hearth steel about 2100 lbs. should be deducted from the above. I should add, however, that on this material my observations are few as compared with those on the former.

Carbon is credited with a constant effect of 800 lbs. per each 0.01 per cent.

Phosphorus shows greater effect in high-carbon than in low-carbon steels. For 0.07 and 0.08 of carbon it has about the same effect as carbon—that is, 800 lbs. for each 0.01 of phosphorus. This increases to 1500 lbs. per 0.01 of phosphorus in 0.15 carbon steel, or nearly twice the effect of carbon. This increase in the

effect of phosphorus as carbon increases is gradual, proceeding about as follows :—

For Carbon. Hundredths per Cent.	Increase of Ultimate Strength per 0·01 per Cent. P. Added. Lbs. per Square Inch.	Effect of Unit of P. to Unit of C. as 1 to
9	900	1½
10	1,000	1½
11	1,100	1¾
12	1,200	1½
13	1,300	1½
14	1,400	1½
15	1,500	1½
16	1,500	1½
17	1,500	1½

The effect per unit of manganese seems to decrease as the percentage of this element increases. For instance, steels of 0·20 and 0·30 manganese show greater difference in ultimate strength than steels of 0·50 to 0·60 manganese, all other elements being the same. I have endeavoured to cover this point irrespective of the percentage of carbon and phosphorus, but upon further investigation it may be necessary to take one or both of these elements into account in estimating the effect of high and low manganese.

Assuming the first addition of 0·15 per cent. of manganese to increase the ultimate strength 3600 lbs., we have the following increase in ultimate strength by successive increments of manganese :—

Manganese, per Cent.		Increase in Ultimate Strength.	Total Increase in Ultimate Strength from 0. Manganese.
From	To	Lbs. per Square Inch.	Lbs. per Square Inch.
0·00	0·15	3,600	3,600
0·15	0·20	1,200	4,800
0·20	0·25	1,100	5,900
0·25	0·30	1,000	6,900
0·30	0·35	900	7,800
0·35	0·40	800	8,600
0·40	0·45	700	9,300
0·45	0·50	600	9,900
0·50	0·55	500	10,400
0·55	0·60	500	10,900
0·60	0·60	500	11,400

Sulphur is credited with a constant effect of 500 lbs. for each 0·01 per cent. increase. But the effects of this element are still being carefully considered.

Silicon is so very low in this steel (there being only a trace), that its hardening effect has not been considered at all, but with other steels it should be considered.

The average weight of our ordinary ingots is 5500 lbs. They measure 18 inches by 20 inches, but we are obliged to use many different sizes, which run from 12 by 16 to 10 by 31 inches in rectangles. The heaviest ingots weigh 7000 lbs., and the lightest 3000 lbs.; they have $1\frac{1}{2}$ inch taper in 78 inches. These ingots are charged hot into the soaking-pits and rolled on blooming-mill, then re-heated and rolled into plates.

The test-pieces are sheared $2\frac{1}{2}$ inches wide by 18 inches long, and reduced to a width of $1\frac{1}{2}$ inch to $1\frac{1}{4}$ inch by milling for length of 10 inches. All tests were made on an Olsen lever machine.

The results of the tension tests and full analyses of the 408 basic Bessemer plates under consideration are given in Tables II. and III. The former contains the results of tests of 171 universal plates, and the latter those of 237 sheared plates. The estimated ultimate strength of each plate is given in Column 11 of these tables, these values being deduced from the actual ones, and the differences with proper signs being given in Column 12. In the last column the differences are given after the corrections in estimated ultimate strengths have been made for size of plates. I call particular attention to this, as all of my other tables in this paper are based on these figures.

In my first work, the tests of the universal-mill plates were kept separate from those of sheared-mill plates, and the results grouped for each 0.01 per cent. of carbon, sulphur, and phosphorus, and each 0.05 per cent. of manganese.* But I found this was not necessary, and that by putting the tests of plates from both mills together and dividing them into only three or four groups under each element, much more satisfactory results are obtained, as we have more tests in each group, and can see the effect of the element under consideration much better. In Tables IV. to IX. inclusive, the tests are grouped in this way. An investigation of these tables will show my endeavours to bring out the hardening effects of each element. On the central horizontal line

* These results are given in my papers before the American Institute of Mining Engineers, August 1892 and July 1893.

of each table is given the number of tests in each group of which the actual ultimate strengths come within plus or minus 1000 lbs. of the estimated ultimate strength. On the lines above are given the tests that are 1000 to 2000 lbs. high, next those that are 2000 to 3000 lbs. high, &c., to those that are over 5000 lbs. high. Below are given those that are 1000 to 2000 lbs. low, &c., to those that are over 5000 lbs. low. All these results are subdivided into four groups by thickness of plates, *i.e.*, under $\frac{3}{8}$ -inch, $\frac{3}{8}$ -inch and $\frac{7}{8}$ -inch, $\frac{1}{2}$ -inch and $\frac{9}{16}$ -inch, $\frac{5}{8}$ -inch to 1 inch. Tables IV.A to IX.A are arranged under the same grouping of tests as above, using the differences in actual and estimated ultimate strengths after making corrections for size of plates—that is, the table for each element is in two parts, in order to eliminate the effect of the finishing temperature, and by doing so show the importance of making an allowance for the same.

In Tables X. to XVI. inclusive, the tests of the three or four groups of each element are compared with those of each of the groups of all the other elements. For instance, in the carbon, Table X., the low carbons 0.06 to 0.09 are given in upper part of the table, then 0.10, 0.11, and 0.12 carbons in middle division, and 0.13 to 0.18 carbons in the lower part. The tests in each of these groups of carbons were subdivided into the groups for sulphur, next they were subdivided for each group of phosphorus, &c. On the horizontal lines the tests are arranged as before, those within ± 1000 lbs. on the centre line of each division for carbon, and then 1000 to 3000 lbs. high on the line above, &c., to those over 5000 lbs. high. The tests that are low are arranged in the same manner on the lower lines, each 2000 being used instead of 1000 lbs., in order to get the tests of all groups of each element on same table.

Tables X.A to XVI.A are arranged under the same grouping as in the above tables, using the differences after making the corrections for size of plates, the tables for each element being in two parts as before.

Tables XVII. and XVIII. give the average of the actual ultimate strengths of the tests of each group considered, with the average of the estimated ultimate strengths of same groups. The latter averages are deducted from the former, and the differences

of these averages are given with their proper signs. All the universal plates are given in Table XVII., and all the sheared mill in Table XVIII.

In Table XXI. the tests of both universal and sheared plates are included, but in other respects it is the same as Tables XVII. and XVIII., except in that there are enough tests to give the percentage that come within ± 3000 , ± 4000 , and ± 5000 lbs.

It has been my endeavour in these tables to bring out clearly and to prove the hardening effects of each element, in order to further investigate them. An inspection will show that the estimated ultimate strengths agree very closely in most cases with the actual value; the exception to this is, however, the group of actual ultimate strengths of over 70,000 lbs., which indicated that the table of estimated ultimate strengths is not as accurate for high steels as for low steels, although, after making corrections for the size of plates, the results are materially improved. But in order to settle this point, the tests were grouped by their *estimated ultimate strengths*, and the results show that the table is as accurate for the high steels as for the low.

The indications are that the ultimate strengths of plates with high carbon or high phosphorus are more affected by the finishing temperature than any of the others. In these cases the correction for size of plates gives a gain in the percentage of tests within 5000 lbs. of 8.8 per cent. and 7.3 per cent. respectively. This shows the importance of conducting a series of tests on uniformly annealed test-pieces and eliminating this trouble, but as yet I have not been able to do this.

I have carefully gone over the Tables X., X.A., to XVI., XVI.A, and cannot find any new relations between the elements considered that would improve the accuracy of my table of estimated ultimate strengths. But when a larger series of tests are grouped in this way, they will no doubt develop some important relations between the elements which as yet are not even suspected.

The relation between the elongation and chemical constitution has not as yet been thoroughly investigated, but what little work I have done in this line indicates that the results of such an investigation would be of great value.

The practical application of my table of estimated ultimate

strengths in the manufacture of steel at the works of the Pottstown Iron Company has given very satisfactory results. Out of the last one thousand blows graded in this way, 98 per cent. of them met the requirements of the orders and were accepted. Having the same standard of comparison in use in all departments gives a close check on each step in the process of manufacture, and has enabled us to greatly improve the quality and uniformity of the finished product. If a blow does not give the results as indicated by its chemistry, we follow it back through each process of manufacture, and if the cause of the trouble is not made apparent, we then have a complete analysis made of the drillings from broken test-pieces, and generally locate the trouble.

I have applied my table of estimated ultimate strengths to several lists of published tests—acid Bessemer and acid open-hearth steel—that have complete analyses given, and to steel made by other parties, and rolled at these works and tested here. The results were very satisfactory. For convenience of reference, I have given in Tables XIX. and XX. my table of estimated ultimate strengths, reduced to tons per square inch in the former, and kilogrammes per square millimetre in the latter.

When rolling heavy steel plates, trouble is often caused by finishing them at too high a temperature, which gives a material with crystalline fracture, poor reduction of area, and poor bends. In order to guard against this and control the finishing temperature, we use very light draughts in rolling, and produce as good results in heavy plates as in the light ones. Too much importance cannot be given to the heat-treatment of steel. Mr. H. M. Howe's recent experiments on the subject* are of the greatest value, and it is to be hoped that they will be continued on a larger scale in connection with the work of rolling and forging.

The effects of oxygen on steel are being investigated in a practical manner by Mr. A. Lantz of the Peine Works. He wrote to me as follows last December:—"We have found, during the current year, that oxygen plays an important rôle, till now little observed—such, indeed, that given a like content of carbon, phosphorus, and manganese in the blows, a blow with greater oxygen

* *Transactions of the American Institute of Mining Engineers*, August 1893.

content gives a greater hardness, and less ductility than a blow with less oxygen content.* This fact, which we have here firmly established, is so important for the technical world, that I would strongly recommend it to your consideration. The variations of the oxygen content brings differences of several kilogrammes per square millimetre in strength, other conditions being similar."

The manufacturers of steel castings will be able to give us more assistance in this work than any other set of men, as they have the true starting-point to work from, and do not have to contend with the effect of work. It would, of course, require a large amount of work on their part, but the results obtained would be of the greatest service to all manufacturers and users of steel.

Recent microscopic and other investigations have given new interest to the "Physics of Steel." I give below the lines suggested by Mr. H. M. Howe for discussion at the February meeting of the American Institute of Mining Engineers. They might more properly be termed *suggested lines of investigation*, and it is to be hoped that many of them may be followed up as such:—

THE PHYSICS OF STEEL.

I. Correspondence between chemical composition and fracture, micro-structure and physical properties.

II. Influence of—

- | | | |
|---|--------|--------------------------|
| (1.) Casting temperature. | } on { | (a) Fracture. |
| (2.) Manner and temperature of heating. | | (b) Micro-structure. |
| (a) For rolling. | | (c) Physical properties. |
| (b) For annealing. | | (d) Tensile properties. |
| (3.) Work. | | (e) Residual stress. |
| (4.) Finishing temperature. | | |
| (5.) Rate and mode of cooling. | | |
| (a) After forging. | | |
| (b) For casting. | | |

III. Segregation as affected by—

- (1.) Composition.
- (2.) Casting temperature.
- (3.) Rate of cooling.

* The method used for determining oxygen is that of Professor Ledebur, given in *Stahl und Eisen*, May 1882, p. 193.

IV. Blow-holes and pipes ; their volume and position as affected by—

- (1.) Composition.
- (2.) Casting temperature.
- (3.) Casting pressure.
- (4.) Rate of cooling.
- (5.) Special additions.
- (6.) Forging.

V. Hardening ; relation between tensile properties and hardness of quenched steel, and—

- (1.) Quenching temperature.
- (2.) Quenching medium.
- (3.) Size of piece quenched.

The late Dr. Percy, in his presidential address to this Institute in 1886, said, "I have long been convinced that it is only by physico-chemical investigation that our present ignorance of the cause of many phenomena relating to iron and steel will ever be lessened or dispelled."

The longer we study these phenomena the more clearly and strongly the truth of the above assertion stands forth. If the results which I have obtained should encourage or incite others to take up the investigation and to increase our common store of knowledge, the object of this paper will be accomplished.

TABLE I.—*Estimated Ultimate Strengths.*
Pounds per Square Inch.

Carbon.	'06	'07	'08	'09	'10	'11	'12	'13	'14	'15	'16	'17	'18	'19	'20	'21	'22	'23	'24	'25
Phos. .000	39,550	40,350	41,150	41,950	42,750	43,550	44,350	45,150	45,950	46,750	47,550	48,350	49,150	49,950	50,750	51,550	52,350	53,150	53,950	54,750
" .005	39,950	40,750	41,550	42,400	43,250	44,100	44,950	45,800	46,650	47,500	48,300	49,100	49,900	50,700	51,500	52,300	53,100	53,900	54,700	55,500
" .01	40,350	41,150	41,950	42,850	43,750	44,650	45,550	46,450	47,350	48,250	49,050	49,850	50,650	51,450	52,250	53,050	53,850	54,650	55,450	56,250
" .015	40,750	41,550	42,350	43,300	44,250	45,200	46,150	47,100	48,050	49,000	49,800	50,600	51,400	52,200	53,000	53,800	54,600	55,400	56,200	57,000
" .02	41,150	41,950	42,750	43,750	44,750	45,750	46,750	47,750	48,750	49,750	50,550	51,350	52,150	52,950	53,750	54,550	55,350	56,150	56,950	57,750
" .025	41,550	42,350	43,150	44,200	45,250	46,300	47,350	48,400	49,450	50,500	51,300	52,100	52,900	53,700	54,500	55,300	56,100	56,900	57,700	58,500
" .03	41,950	42,750	43,550	44,650	45,750	46,850	47,950	49,050	50,150	51,250	52,050	52,850	53,650	54,450	55,250	56,050	56,850	57,650	58,450	59,250
" .035	42,350	43,150	43,950	45,100	46,250	47,400	48,550	49,700	50,850	52,000	52,800	53,600	54,400	55,200	56,000	56,800	57,600	58,400	59,200	60,000
" .04	42,750	43,550	44,350	45,550	46,750	47,950	49,150	50,350	51,550	52,750	53,550	54,350	55,150	55,950	56,750	57,550	58,350	59,150	59,950	60,750
" .045	43,150	43,950	44,750	46,000	47,250	48,500	49,750	51,000	52,250	53,500	54,300	55,100	55,900	56,700	57,500	58,300	59,100	59,900	60,700	61,500
" .05	43,550	44,350	45,150	46,450	47,750	49,050	50,350	51,650	52,950	54,250	55,050	55,850	56,650	57,450	58,250	59,050	59,850	60,650	61,450	62,250
" .055	43,950	44,750	45,550	46,900	48,250	49,600	50,950	52,300	53,650	55,000	55,800	56,600	57,400	58,200	59,000	59,800	60,600	61,400	62,200	63,000
" .06	44,350	45,150	45,950	47,350	48,750	50,150	51,550	52,950	54,350	55,750	56,550	57,350	58,150	58,950	59,750	60,550	61,350	62,150	62,950	63,750
" .065	44,750	45,550	46,350	47,800	49,250	50,700	52,150	53,600	55,050	56,500	57,300	58,100	58,900	59,700	60,500	61,300	62,100	62,900	63,700	64,500
" .07	45,150	45,950	46,750	48,250	49,750	51,250	52,750	54,250	55,750	57,250	58,050	58,850	59,650	60,450	61,250	62,050	62,850	63,650	64,450	65,250
" .075	45,550	46,350	47,150	48,700	50,250	51,800	53,350	54,900	56,450	58,000	58,800	59,600	60,400	61,200	62,000	62,800	63,600	64,400	65,200	66,000
" .08	45,950	46,750	47,550	49,150	50,750	52,350	53,950	55,550	57,150	58,750	59,550	60,350	61,150	61,950	62,750	63,550	64,350	65,150	65,950	66,750
" .085	46,350	47,150	47,950	49,600	51,250	52,900	54,550	56,200	57,850	59,500	60,300	61,100	61,900	62,700	63,500	64,300	65,100	65,900	66,700	67,500
" .09	46,750	47,550	48,350	50,050	51,750	53,450	55,150	56,850	58,550	60,250	61,050	61,850	62,650	63,450	64,250	65,050	65,850	66,650	67,450	68,250
" .095	47,150	47,950	48,750	50,500	52,250	54,000	55,750	57,500	59,250	61,000	61,800	62,600	63,400	64,200	65,000	65,800	66,600	67,400	68,200	69,000
" .10	47,550	48,350	49,150	50,950	52,750	54,550	56,350	58,150	59,950	61,750	62,550	63,350	64,150	64,950	65,750	66,550	67,350	68,150	68,950	69,750
.001 Phos. =	80	80	80	90	100	110	120	130	140	150	150	150	150	150	150	150	150	150	150	150

TABLE I. (continued).—Additions for Manganese.

Man.	Lbs.	Man.	Lbs.	Man.	Lbs.	Man.	Lbs.	Man.	Lbs.	Man.	Lbs.
...	...	21	5,020	31	7,080	41	8,740	51	10,000	61	11,000
...	...	215	5,130	315	7,170	415	8,810	515	10,050	615	11,050
...	...	22	5,240	32	7,260	42	8,880	52	10,100	62	11,100
...	...	225	5,350	325	7,350	425	8,950	525	10,150	625	11,150
...	...	23	5,460	33	7,440	43	9,020	53	10,200	63	11,200
...	...	235	5,570	335	7,530	435	9,090	535	10,250	635	11,250
...	...	24	5,680	34	7,620	44	9,160	54	10,300	64	11,300
...	...	245	5,790	345	7,710	445	9,230	545	10,350	645	11,350
15	3,600	25	5,900	35	7,800	45	9,300	55	10,400	65	11,400
155	3,720	255	6,000	355	7,880	455	9,360	555	10,450	655	11,450
16	3,840	26	6,100	36	7,960	46	9,420	56	10,500	66	11,500
165	3,960	265	6,200	365	8,040	465	9,480	565	10,550	665	11,550
17	4,080	27	6,300	37	8,120	47	9,540	57	10,600	67	11,600
175	4,200	275	6,400	375	8,200	475	9,600	575	10,650	675	11,650
18	4,320	28	6,500	38	8,280	48	9,660	58	10,700	68	11,700
185	4,440	285	6,600	385	8,360	485	9,720	585	10,750	685	11,750
19	4,560	29	6,700	39	8,440	49	9,780	59	10,800	69	11,800
195	4,680	295	6,800	395	8,520	495	9,840	595	10,850	695	11,850
20	4,800	30	6,900	40	8,600	50	9,900	60	10,900	70	11,900
205	4,920	305	6,990	405	8,670	505	9,950	605	10,950	705	11,950

TABLE I. (continued).—Additions for Sulphur.

	0	001	002	003	004	005	006	007	008	009
0	000	50	100	150	200	250	300	350	400	450
01	500	550	600	650	700	750	800	850	900	950
02	1,000	1,050	1,100	1,150	1,200	1,250	1,300	1,350	1,400	1,450
03	1,500	1,550	1,600	1,650	1,700	1,750	1,800	1,850	1,900	1,950
04	2,000	2,050	2,100	2,150	2,200	2,250	2,300	2,350	2,400	2,450
05	2,500	2,550	2,600	2,650	2,700	2,750	2,800	2,850	2,900	2,950
06	3,000	3,050	3,100	3,150	3,200	3,250	3,300	3,350	3,400	3,450
07	3,500	3,550	3,600	3,650	3,700	3,750	3,800	3,850	3,900	3,950

TABLE II.—*Universal Mill Plates.*

No. of Tests.	Size of Plates, Inches.	Elastic Limit.	Ultimate Strength.	Per Ct. Elong. in 8 in.	Per Ct. Reduction.	Analysis.				Estimated by Table.		Difference after Correcting for Size.
						C.	S.	P.	Mn.	Ultimate Strength.	Difference.	
1	20 x 12	33,400	51,080	31.75	71.1	.06	.037	.020	.400	51,600	- 520	+ 480
2	20 x 12	31,550	49,900	30.75	59.4	.06	.057	.025	.230	49,860	+ 40	+1,040
3	12 x 12	32,440	53,050	31.50	71.3	.06	.037	.030	.310	50,880	+2,170	+3,170
4	20 x 12	32,010	51,910	33.50	68.5	.06	.048	.050	.330	53,370	-1,460	+ 40
5	11 x 12	29,970	49,670	33.75	68.4	.07	.041	.020	.325	51,350	-1,680	- 180
6	11 x 12	30,610	51,030	32.75	66.1	.07	.046	.025	.403	53,292	-2,262	-1,262
7	20 x 12	30,810	51,490	35.00	75.5	.07	.033	.025	.313	51,134	+ 356	+1,356
8	20 x 12	31,540	52,880	31.25	68.8	.07	.050	.025	.325	52,200	+ 680	+2,180
9	18 x 12	39,040	56,950	26.50	56.1	.07	.050	.030	.395	53,770	+3,180	+3,180
10	20 x 12	30,610	51,430	35.00	73.5	.07	.038	.035	.415	53,860	-2,430	-1,430
11	16 x 12	33,080	56,520	28.75	53.5	.07	.060	.055	.615	58,800	-2,280	- 780
12	20 x 12	31,980	53,040	30.00	65.5	.08	.048	.005	.405	52,620	+ 420	+1,920
13	12 x 12	31,640	49,910	33.50	66.3	.08	.048	.015	.465	54,730	-4,820	-3,320
14	16 x 12	32,250	51,640	32.50	48.7	.08	.047	.015	.155	48,420	+3,220	+4,220
15	20 x 12	37,520	55,360	28.75	56.3	.08	.043	.020	.365	52,940	+2,420	+2,420
16	20 x 12	30,420	50,710	31.25	67.7	.08	.037	.020	.430	53,620	-2,910	-1,910
17	24 x 12	29,560	52,540	30.00	76.5	.08	.031	.020	.425	53,250	- 710	+ 790
18	15 x 12	30,350	51,760	28.50	66.3	.08	.058	.025	.270	52,350	- 590	+1,410
19	20 x 12	31,460	52,150	31.25	65.6	.08	.046	.025	.355	53,330	-1,180	+ 320
20	18 x 12	31,050	52,280	32.50	68.1	.08	.021	.030	.350	52,400	- 120	+1,380
21	22 x 12	30,000	50,000	31.00	65.4	.08	.066	.030	.412	55,618	-5,618	-4,118
22	17 x 12	32,100	59,530	31.25	54.9	.08	.031	.030	.730	57,300	+2,230	+3,730
23	26 x 12	20,470	51,080	20.00	67.0	.08	.042	.030	.445	54,880	-3,800	-2,800
24	23 x 12	34,960	51,580	31.25	66.8	.08	.048	.030	.355	53,830	-2,250	-2,250
25	11 x 12	29,260	51,640	32.00	63.7	.08	.036	.035	.390	54,190	-2,550	- 550
26	20 x 12	36,558	54,870	29.25	70.0	.08	.064	.035	.610	57,150	-2,280	-1,280
27	26 x 12	34,760	54,980	31.25	70.1	.08	.041	.040	.380	54,680	+ 300	+2,300
28	15 x 12	32,620	51,070	29.75	55.7	.08	.051	.040	.410	55,640	-4,570	-3,570
29	18 x 12	37,330	52,720	30.00	63.1	.08	.040	.040	.505	56,300	-3,580	-3,080
30	24 x 12	39,830	58,700	28.75	58.9	.08	.063	.040	.510	57,500	+1,200	+2,200
31	7 x 12	34,320	54,320	28.50	66.7	.08	.032	.050	.280	53,250	+1,070	+2,070
32	22 x 12	28,920	51,680	31.75	70.0	.08	.062	.055	.304	55,622	-3,942	-3,942
33	24 x 12	36,590	58,140	28.25	57.3	.08	.057	.055	.480	58,060	+ 80	+1,080
34	18 x 12	41,640	60,630	25.00	55.2	.08	.071	.075	.445	59,930	+ 700	+ 700
35	17 x 12	33,270	51,490	31.25	65.7	.09	.052	.015	.380	54,180	-2,690	-1,190
36	30 x 12	32,280	55,120	30.25	64.8	.09	.055	.020	.375	54,700	+ 420	+ 420
37	20 x 12	34,090	54,770	31.75	61.4	.09	.061	.020	.425	56,390	-1,620	-1,120
38	13 x 12	36,360	55,560	30.00	63.4	.09	.053	.025	.455	56,210	- 650	+ 350
39	20 x 12	32,390	57,090	29.25	58.5	.09	.063	.030	.363	55,808	+1,282	+2,282
40	14 x 12	33,880	49,750	33.75	62.3	.09	.047	.030	.355	54,880	-5,130	-3,130
41	14 x 12	31,300	52,620	31.25	61.4	.09	.043	.030	.333	54,294	-1,674	+ 76
42	20 x 12	32,670	52,300	32.50	72.3	.09	.036	.030	.275	52,850	- 550	+ 950
43	16 x 12	37,370	59,250	30.00	56.9	.09	.057	.040	.665	59,950	- 700	- 700
44	19 x 12	37,030	58,940	27.75	58.1	.09	.044	.040	.640	59,050	- 110	+ 890
45	15 x 12	30,260	55,040	29.50	55.2	.09	.058	.045	.365	56,940	-1,900	- 150
46	20 x 12	33,800	58,600	27.00	62.2	.09	.043	.045	.507	58,120	+ 480	+1,480
47	30 x 12	35,890	58,320	27.50	55.5	.09	.046	.050	.355	56,630	+1,690	+3,690
48	30 x 12	36,780	56,640	25.50	49.3	.09	.060	.050	.410	58,190	-1,550	+ 450
49	13 x 12	34,760	60,320	27.50	62.1	.09	.053	.050	.588	59,880	+ 440	+1,440
50	20 x 12	31,140	56,400	29.75	58.5	.09	.036	.050	.348	56,014	+ 386	+2,136
51	7 x 12	35,130	63,510	23.00	55.1	.09	.038	.050	.430	57,370	+6,140	+3,140
52	7 x 12	35,290	62,840	21.25	54.8	.09	.067	.050	.370	57,920	+4,920	+1,920
53	24 x 12	41,640	64,830	22.50	58.2	.09	.033	.050	.735	60,350	+4,480	+4,480
54	30 x 12	33,760	59,590	28.00	58.8	.09	.042	.050	.445	57,780	+1,810	+1,810
55	16 x 12	31,130	53,310	33.00	63.0	.09	.057	.050	.460	58,720	-5,410	-3,910
56	30 x 12	31,140	57,480	21.50	39.0	.09	.063	.060	.200	55,300	+2,180	+4,180
57	14 x 12	32,020	55,260	28.75	61.4	.09	.041	.060	.535	59,650	-4,390	-2,390

TABLE II.—(continued).

No. of Tests.	Size of Plates, Inches.	Elastic Limit.	Ultimate Strength.	Per Ct. Elong. in 8 in.	Per Ct. Reduction.	Analysis.				Estimated by Table.		Difference after Correcting for Size.
						C.	S.	P.	Mn.	Ultimate Strength.	Difference.	
58	14 x 1/2	33,450	58,320	33.25	63.8	.09	.031	.065	.515	59,400	-1,080	+ 170
59	28 1/2 x 1/2	35,480	63,740	27.00	42.3	.09	.059	.065	.480	60,410	+3,330	+4,330
60	18 x 1/2	33,330	60,530	27.75	47.0	.09	.070	.070	.505	61,700	-1,170	+ 830
61	28 1/2 x 1/2	41,140	66,760	22.75	50.7	.09	.077	.075	.325	59,900	+5,860	+2,860
62	15 x 1/2	36,010	58,110	27.50	52.4	.09	.050	.080	.445	60,880	-2,770	-2,770
63	14 x 1/2	36,120	64,090	26.25	48.2	.09	.063	.080	.650	63,700	+ 390	+1,390
64	20 x 1/2	35,300	64,040	27.50	50.9	.09	.055	.080	.295	58,700	+5,340	+7,340
65	16 x 1/2	38,670	59,570	27.50	57.6	.09	.048	.085	.603	62,930	-3,360	-2,360
66	10 x 1/2	37,260	62,920	22.50	46.9	.09	.052	.090	.380	60,930	+1,990	+1,990
67	14 x 1/2	32,490	60,980	25.50	54.8	.09	.038	.090	.558	62,430	-1,450	- 200
68	16 x 1/2	34,250	56,370	29.50	56.7	.10	.063	.005	.510	56,400	- 30	+ 470
69	24 x 1/2	33,970	53,690	32.50	63.1	.10	.053	.020	.525	57,550	-3,860	-3,860
70	15 x 1/2	34,910	60,900	26.50	47.2	.10	.077	.025	.570	59,700	+1,200	+2,700
71	12 x 1/2	32,450	57,760	28.00	60.1	.10	.051	.025	.458	57,196	+ 564	+1,814
72	17 x 1/2	40,450	61,060	26.00	57.2	.10	.005	.025	.400	54,100	+6,960	+6,960
73	30 x 1/2	33,990	60,820	28.00	50.8	.10	.055	.030	.365	56,540	+4,280	+6,280
74	26 1/2 x 1/2	36,330	62,820	21.25	47.9	.10	.070	.030	.478	58,886	+3,934	+5,434
75	20 x 1/2	39,440	59,160	25.00	58.7	.10	.069	.030	.583	59,930	- 770	- 270
76	16 x 1/2	32,670	58,050	26.75	56.5	.10	.055	.035	.528	59,180	-1,130	- 130
77	22 x 1/2	37,580	56,770	28.00	62.0	.10	.050	.035	.465	58,230	-1,460	- 460
78	20 x 1/2	30,450	58,920	27.75	51.3	.10	.051	.040	.373	57,468	+1,452	+2,702
79	26 x 1/2	41,640	63,090	18.50	58.0	.10	.066	.040	.410	58,790	+4,300	+1,300
80	16 x 1/2	32,030	57,030	30.50	56.7	.10	.053	.040	.635	60,650	-3,620	-2,120
81	25 x 1/2	34,980	57,820	27.50	58.5	.10	.050	.040	.465	58,730	-1,410	- 410
82	22 x 1/2	31,830	58,990	25.25	54.3	.10	.058	.040	.350	57,450	+1,540	+3,040
83	18 x 1/2	32,200	58,000	28.75	50.3	.10	.041	.045	.435	58,390	- 390	+1,360
84	16 x 1/2	34,360	56,760	32.00	61.4	.10	.030	.045	.513	58,780	-2,020	-1,020
85	12 x 1/2	38,810	58,220	27.75	59.8	.10	.054	.045	.395	58,470	- 250	+ 250
86	22 x 1/2	36,890	56,310	30.00	59.2	.10	.049	.050	.480	59,860	-3,550	-2,550
87	30 x 1/2	32,490	57,770	27.50	46.4	.10	.035	.060	.480	59,160	-1,390	+ 610
88	20 x 1/2	38,390	63,580	29.50	54.0	.10	.053	.060	.590	61,200	+2,380	+2,880
89	16 x 1/2	35,100	57,760	31.25	59.6	.10	.055	.055	.650	62,400	-4,640	-3,640
90	12 1/2 x 1/2	36,640	58,190	27.00	51.9	.10	.070	.060	.660	63,750	-5,560	-4,560
91	10 1/2 x 1/2	38,070	65,590	25.00	49.7	.10	.072	.060	.498	62,226	+3,364	+3,864
92	24 x 1/2	37,140	65,080	23.00	48.4	.10	.070	.060	.503	62,180	+2,900	+2,900
93	20 x 1/2	34,540	63,660	23.50	46.2	.10	.041	.060	.595	61,650	+2,010	+3,510
94	14 1/2 x 1/2	35,540	63,640	23.75	59.5	.10	.060	.060	.510	61,750	+1,890	+1,890
95	24 x 1/2	34,420	61,060	28.50	59.0	.10	.057	.065	.390	60,540	+ 520	+2,520
96	16 x 1/2	35,410	63,520	26.50	53.2	.10	.051	.065	.520	61,900	+1,620	+1,620
97	8 x 1/2	33,580	64,180	23.50	45.5	.10	.047	.065	.615	62,650	+1,630	+2,780
98	20 x 1/2	39,030	65,820	25.00	50.3	.10	.065	.070	.400	61,600	+4,220	+4,720
99	18 x 1/2	33,600	56,180	30.00	59.4	.10	.048	.075	.355	60,530	-4,350	-4,350
100	20 x 1/2	37,170	59,640	27.25	54.3	.10	.068	.075	.400	62,250	-2,610	-2,110
101	16 x 1/2	38,550	66,660	24.50	46.2	.10	.059	.075	.575	63,850	+2,810	+3,310
102	16 x 1/2	36,610	65,860	23.00	40.9	.10	.056	.080	.515	63,600	+2,260	+3,260
103	28 1/2 x 1/2	36,850	64,340	25.00	47.0	.10	.077	.080	.565	65,150	- 810	+ 190
104	12 1/2 x 1/2	35,140	54,810	28.75	50.2	.11	.073	.030	.335	58,030	-3,220	-2,220
105	14 x 1/2	33,460	55,840	27.50	51.6	.11	.046	.030	.373	57,318	-1,478	+ 272
106	18 x 1/2	32,970	56,450	29.25	52.6	.11	.071	.035	.475	60,550	-4,100	-2,100
107	10 x 1/2	38,330	64,450	24.50	43.6	.11	.065	.040	.518	61,280	+3,170	+3,170
108	24 x 1/2	32,910	60,360	28.00	47.8	.11	.051	.040	.365	58,540	+1,820	+3,820
109	30 x 1	...	57,230	24.00	51.3	.11	.042	.045	.355	58,480	-1,250	+ 750
110	11 x 1/2	40,860	55,700	26.50	59.7	.11	.065	.045	.393	60,238	-4,538	-4,038
111	20 x 1/2	37,950	65,250	28.25	56.1	.11	.036	.050	.583	61,580	+3,670	+4,670
112	8 x 1/2	38,430	62,940	23.75	45.7	.11	.052	.060	.610	62,650	+ 290	+1,290
113	16 x 1/2	34,860	60,310	22.50	33.8	.11	.052	.055	.590	63,000	-2,560	-2,560
114	20 x 1/2	34,720	58,570	31.00	58.3	.11	.062	.055	.605	63,650	-5,080	-4,580

TABLE II.—(continued).

No. of Tests.	Size of Plates, Inches.	Elastic Limit.	Ultimate Strength.	Per Ct. Elong. in 8 in.	Per Ct. Reduction.	Analysis.				Estimated by Table.		Difference after Correcting for Size.
						C.	S.	P.	Mn.	Ultimate Strength.	Difference.	
115	24 x 15	39,380	65,070	26.75	45.4	11	.075	.055	.538	63,630	+1,440	+1,440
116	23½ x 15	36,000	61,330	28.50	52.0	11	.071	.060	.585	64,450	-3,120	-3,120
117	11 x 15	30,450	57,850	30.50	59.6	11	.042	.060	.610	63,250	-5,400	-3,900
118	30 x 15	35,590	59,510	27.75	54.8	11	.035	.060	.385	60,260	-750	+1,250
119	24 x 15	34,390	57,430	26.25	54.9	11	.051	.065	.297	60,090	-2,660	-660
120	12 x 15	34,120	65,090	25.75	51.4	11	.070	.070	.453	64,086	+1,004	+1,004
121	16 x 15	40,250	71,570	19.25	48.9	11	.073	.075	.625	66,600	+4,970	+1,970
122	24 x 15	42,340	65,240	25.00	42.7	11	.059	.075	.485	64,470	+770	+770
123	10 x 15	38,030	62,530	30.50	63.3	11	.036	.080	.433	63,212	-682	+568
124	7½ x 15	38,230	63,400	27.25	46.8	11	.034	.085	.457	63,984	-584	-84
125	26 x 15	33,490	67,580	23.00	44.4	11	.076	.085	.435	65,760	+1,820	+3,820
126	14 x 15	35,300	64,700	25.00	44.4	11	.068	.085	.453	65,636	-936	+1,064
127	23½ x 15	35,980	58,130	32.00	60.1	12	.044	.025	.505	59,500	-1,370	-1,370
128	19½ x 15	33,330	57,200	28.75	53.8	12	.079	.025	.268	57,560	-360	+640
129	24 x 15	40,620	61,460	26.50	50.0	12	.063	.025	.535	60,750	+710	+1,710
130	14½ x 15	33,660	57,230	28.00	54.8	12	.062	.030	.510	61,050	-3,820	-2,820
131	11 x 15	37,020	58,350	25.25	54.5	12	.071	.035	.405	60,770	-2,420	-1,420
132	18 x 15	36,900	60,770	30.00	44.4	12	.054	.045	.365	60,490	+280	+1,780
133	30 x 15	30,880	61,220	29.00	50.6	12	.034	.045	.395	59,970	+1,250	+3,250
134	30 x 15	33,330	57,820	26.75	52.0	12	.038	.045	.385	60,010	-2,190	-190
135	30 x 15	33,040	56,380	27.50	50.1	12	.050	.045	.380	60,530	-4,150	-2,150
136	30 x 15	37,890	61,090	25.50	53.6	12	.058	.045	.410	61,390	-300	-300
137	14 x 15	36,030	59,160	28.00	57.5	12	.056	.050	.612	64,160	-5,000	-9,000
138	18 x 15	37,010	64,310	25.00	53.3	12	.049	.050	.495	62,640	+1,670	+1,670
139	10½ x 15	37,500	63,550	25.00	48.4	12	.073	.055	.585	65,350	-1,800	-1,800
140	25 x 15	34,650	60,400	25.00	51.5	12	.055	.060	.513	64,330	-3,930	-2,930
141	20 x 15	36,970	63,990	28.00	53.5	12	.054	.060	.448	63,522	+468	+968
142	10½ x 15	37,230	67,970	21.50	52.8	12	.079	.060	.460	64,920	+3,050	+3,550
143	10 x 15	35,900	64,420	26.00	42.3	12	.058	.065	.315	62,220	+2,200	+3,700
144	26 x 15	33,270	59,890	28.75	61.7	12	.040	.065	.430	63,170	-3,280	-2,280
145	20 x 15	36,670	74,000	23.75	46.9	12	.055	.080	.550	67,100	+6,900	+7,400
146	17 x 15	30,540	63,320	24.75	47.7	12	.073	.085	.485	67,920	-4,600	-2,600
147	26 x 15	42,200	72,780	23.50	45.9	12	.064	.090	.545	68,700	+4,080	+1,080
148	28 x 15	38,550	70,970	23.25	33.4	12	.079	.090	.588	69,880	+1,090	+2,590
149	20 x 15	34,380	60,300	23.75	57.5	12	.047	.090	.330	64,940	-4,640	-2,890
150	30 x 15	31,470	60,610	26.25	42.6	13	.043	.030	.480	60,860	-250	+1,750
151	23½ x 15	31,170	60,540	27.50	48.4	13	.056	.030	.540	62,150	-1,610	+390
152	28 x 15	34,510	60,000	27.50	55.1	13	.035	.035	.495	61,320	-1,320	-320
153	30 x 15	33,230	59,380	25.00	49.2	13	.046	.045	.445	62,530	-3,150	-1,150
154	16 x 15	33,140	64,000	24.25	44.2	13	.077	.060	.525	66,950	-2,950	-1,950
155	24 x 15	30,570	59,910	29.00	61.9	13	.045	.060	.365	63,240	-3,330	-1,330
156	13 x 15	38,230	69,620	25.75	44.9	13	.075	.065	.395	65,870	+3,750	+5,000
157	21 x 15	38,570	70,740	25.00	49.7	13	.055	.070	.667	68,570	+2,170	+2,170
158	27½ x 15	35,310	60,050	27.50	63.6	14	.060	.025	.290	59,150	+900	+1,900
159	30 x 15	31,090	61,660	24.25	48.9	14	.050	.035	.610	64,350	-2,690	-690
160	26 x 15	33,330	60,420	27.00	51.2	14	.052	.035	.360	61,410	-990	+10
161	20 x 15	43,060	62,920	26.00	42.1	14	.064	.045	.560	65,950	-3,030	-2,530
162	20 x 15	30,170	60,520	26.75	44.3	14	.049	.045	.405	63,370	-2,850	-1,100
163	30 x 15	28,500	60,630	23.50	42.7	14	.058	.045	.390	63,590	-2,960	-960
164	26 x 15	33,650	61,540	27.00	47.3	14	.060	.055	.420	65,530	-3,990	-2,990
165	20 x 15	38,800	67,240	21.25	26.2	15	.070	.030	.260	60,850	+6,390	+7,890
166	16 x 15	39,730	62,220	27.75	44.4	15	.028	.049	.436	64,604	-2,384	-384
167	18 x 15	43,740	72,750	24.00	43.7	16	.063	.060	.533	69,930	+2,820	+3,320
168	22 x 15	36,830	74,220	20.50	46.2	16	.063	.070	.670	72,800	+1,420	+1,420
169	16 x 15	37,600	73,800	22.00	44.0	16	.053	.095	.435	73,470	+330	+1,330
170	30 x 15	35,290	79,600	19.75	47.4	18	.052	.095	.615	77,050	+2,550	+2,550
171	26 x 15	37,500	74,180	24.50	33.0	19	.054	.070	.490	72,930	+1,250	+2,250

TABLE III.—112-inch Sheared Mill Plates

No. of Tests.	Size of Plates, Inches.	Elastic Limit.	Ultimate Strength.	Per Ct. Elong. in 8 In.	Per Ct. Reduction.	Analysis.			Estimated by Table.		Difference after Correcting for Size.	
						C.	P.	Mn.	Ultimate Strength.	Difference.		
1	13½ × 24	31,800	53,950	35.00	71.5	.06	.033	.030	.375	51,800	+2,150	+3,150
2	84 × 24	40,629	56,680	30.00	61.3	.06	.056	.030	.378	52,994	+3,682	+2,682
3	65½ × 24	30,750	49,100	28.75	63.3	.07	.033	.015	.345	50,910	-1,810	-1,810
4	35½ × 24	32,720	51,670	35.25	65.8	.07	.035	.015	.350	51,100	+570	+570
5	33 × 24	31,860	49,020	33.00	62.4	.07	.037	.015	.440	52,560	-3,540	-3,040
6	73 × 24	33,780	51,170	27.50	62.5	.07	.065	.015	.612	55,820	-4,650	-5,650
7	39½ × 24	33,180	51,190	31.25	70.1	.07	.047	.020	.250	50,200	+990	+1,490
8	65 × 24	30,020	51,750	30.00	61.1	.07	.041	.020	.323	51,314	+436	+1,686
9	19½ × 24	31,870	52,190	32.50	66.7	.07	.069	.020	.270	51,700	+490	+1,490
10	35½ × 24	30,550	50,550	33.00	72.2	.07	.030	.020	.345	51,610	-1,060	-1,060
11	41 × 24	33,640	53,160	31.75	69.9	.07	.061	.020	.385	53,360	-200	-200
12	78 × 24	39,250	55,510	25.50	64.1	.07	.029	.025	.453	53,136	+2,374	+1,374
13	54 × 24	32,570	51,840	34.25	73.6	.07	.026	.030	.310	51,130	+710	+710
14	41½ × 24	33,780	51,660	23.00	75.8	.07	.060	.030	.255	51,750	-90	-3,090
15	78 × 24	36,750	53,280	31.75	66.1	.07	.046	.030	.273	51,410	+1,870	+870
16	58½ × 24	31,370	52,960	30.50	59.8	.07	.059	.030	.405	54,370	-1,410	-1,410
17	55 × 24	31,840	52,840	36.75	66.3	.07	.075	.030	.410	55,240	-2,400	-2,400
18	38 × 24	35,010	56,900	26.25	55.8	.07	.033	.035	.560	55,300	+1,600	+1,600
19	64½ × 24	35,860	57,420	23.75	56.9	.07	.033	.040	.395	53,720	+3,700	+3,700
20	87 × 25	30,830	52,170	29.75	67.0	.07	.039	.040	.355	53,380	-1,210	-710
21	35½ × 24	32,120	52,230	30.75	63.1	.07	.038	.040	.295	52,250	-20	-20
22	33 × 17½	32,240	49,750	29.25	60.7	.07	.074	.045	.155	51,370	-1,620	-1,120
23	65 × 24	33,510	52,900	32.00	61.7	.07	.064	.045	.380	55,430	-2,530	-2,530
24	72 × 24	38,120	57,290	24.00	69.1	.07	.063	.055	.320	55,160	+2,130	-1,870
25	35½ × 24	36,030	53,150	22.00	65.8	.07	.031	.060	.328	54,104	-954	-954
26	41 × 24	29,550	47,620	32.50	70.4	.08	.064	.005	.230	50,210	-2,590	-2,590
27	60 × 24	31,140	51,900	30.00	65.1	.08	.046	.015	.305	51,640	-540	-540
28	24½ × 24	34,640	52,810	27.50	68.7	.08	.067	.015	.340	53,320	-510	-510
29	36 × 24	31,770	49,450	32.50	71.0	.08	.021	.015	.355	51,280	-1,830	-1,830
30	44 × 24	31,310	49,360	35.00	71.1	.08	.036	.015	.360	52,110	-2,750	-2,750
31	52 × 20	33,250	49,170	29.50	46.8	.08	.040	.015	.385	52,710	-3,540	-2,540
32	50½ × 24	31,800	50,510	32.00	65.1	.08	.055	.015	.383	53,428	-2,918	-2,918
33	41½ × 24	34,110	52,070	30.75	65.2	.08	.034	.015	.440	53,210	-1,140	-1,140
34	60 × 15	31,170	51,010	32.50	67.3	.08	.045	.015	.490	54,380	-3,370	-3,370
35	38 × 24	40,270	56,710	27.75	54.0	.08	.045	.015	.520	54,700	+2,010	+2,010
36	72½ × 15	35,770	50,130	32.50	66.6	.08	.032	.020	.260	50,450	-320	-1,320
37	39½ × 24	36,060	52,780	27.50	64.2	.08	.043	.025	.415	54,110	-1,330	-80
38	30 × 24	30,230	51,770	26.00	71.4	.08	.037	.025	.235	50,570	+1,200	+3,200
39	65 × 15	33,750	53,510	31.75	67.0	.08	.064	.025	.518	56,430	-2,920	-2,920
40	66 × 24	33,860	51,790	27.75	64.9	.08	.037	.030	.370	53,520	-1,730	-230
41	72 × 24	31,850	51,730	32.50	61.4	.08	.049	.030	.380	54,280	-2,550	-2,550
42	62½ × 24	43,580	57,770	23.25	64.5	.08	.045	.030	.385	54,160	+3,610	+610
43	89½ × 24	31,670	47,680	31.25	67.6	.08	.046	.030	.188	50,360	-2,680	-3,680
44	35½ × 24	33,610	49,720	32.50	66.9	.08	.063	.030	.270	53,000	-3,280	-2,280
45	47 × 18½	36,620	56,320	29.25	54.4	.08	.055	.030	.545	56,650	-330	+670
46	47 × 26	32,250	55,250	30.50	60.5	.08	.044	.030	.380	54,030	+1,220	+2,720
47	14 × 24	32,100	57,940	31.00	40.2	.08	.046	.035	.590	57,050	+890	+2,390
48	38 × 24	38,840	58,250	25.75	60.8	.08	.021	.035	.500	54,900	+3,350	+3,350
49	24½ × 24	33,690	52,870	31.00	64.2	.08	.053	.035	.360	54,560	-1,690	-1,690
50	34 × 24	34,390	57,250	27.50	63.6	.08	.043	.035	.503	56,020	+1,220	+1,220

TABLE III.—*Continued.*

No. of Tests.	Size of Plates, Inches.	Elastic Limit.	Ultimate Strength.	Per Ct. Elong. in 8 In.	Per Ct. Reduction.	Analysis.				Estimated by Table.		Difference after Correcting for Size.
						C.	S.	P.	Mn.	Ultimate Strength.	Difference.	
51	40 x	31,290	51,370	31.00	64.3	.08	.040	.035	.355	53,830	-2,460	-1,460
52	78 x	37,480	57,920	25.25	65.4	.08	.041	.035	.495	55,840	+2,080	+1,080
53	32 x	32,410	53,330	31.50	62.4	.08	.050	.040	.520	56,950	-3,620	-3,620
54	25½ x	30,980	58,260	29.25	60.7	.08	.064	.040	.515	57,600	+660	+660
55	36 x	35,950	54,780	32.00	66.0	.08	.035	.040	.340	53,720	+1,060	+1,060
56	61 x 26	32,190	52,000	25.00	43.1	.08	.025	.045	.425	54,950	-2,950	-1,450
57	35½ x	35,060	57,760	31.00	65.8	.08	.036	.045	.450	55,850	+1,910	+1,910
58	...	35,130	56,090	29.25	70.5	.08	.064	.045	.290	54,650	+1,440	+1,440
59	36 x	34,600	56,060	29.50	65.1	.08	.044	.045	.330	54,390	+1,670	-1,330
60	72 x	39,640	57,120	25.75	63.8	.08	.039	.050	.380	55,380	+1,740	+740
61	42 x	35,140	57,190	26.25	56.8	.08	.039	.050	.382	55,412	+1,778	+1,222
62	51 x 22½	34,900	58,540	30.00	58.0	.08	.044	.050	.505	57,300	+1,240	+2,490
63	52 x 16½	33,020	55,660	29.75	55.9	.08	.040	.050	.590	57,950	-2,290	-1,790
64	60 x 16½	33,500	56,310	28.75	59.2	.08	.043	.060	.440	57,260	-950	-450
65	35 x	38,540	58,270	30.00	61.2	.08	.039	.060	.470	57,440	+830	+830
66	60 x	35,960	58,530	27.75	57.7	.08	.059	.060	.460	58,320	+210	+210
67	32 x	31,670	61,030	26.75	47.3	.08	.068	.065	.510	59,750	+1,280	+1,280
68	15½ x	38,160	63,160	21.25	53.9	.08	.070	.075	.305	57,640	+5,520	+5,520
69	28½ x	35,720	58,240	27.50	62.6	.08	.041	.080	.340	57,220	+1,020	-1,020
70	60 x	34,740	53,510	22.50	63.2	.09	.031	.005	.265	50,150	+3,360	+3,360
71	33½ x	32,550	52,880	31.25	59.5	.09	.044	.010	.503	54,980	-2,100	-2,100
72	45 x	35,520	60,110	22.50	57.9	.09	.061	.015	.570	56,950	+2,560	+2,560
73	39½ x	34,250	53,200	27.50	61.4	.09	.063	.020	.580	57,600	-4,400	-3,900
74	65 x 24	32,230	58,790	28.25	55.9	.09	.040	.020	.475	55,350	+3,440	+4,690
75	41½ x	35,840	56,820	20.00	63.3	.09	.042	.020	.393	54,338	+2,482	+2,482
76	65 x	29,520	51,220	33.00	62.7	.09	.071	.025	.380	56,030	-4,810	-3,560
77	63½ x	33,330	58,720	21.75	54.6	.09	.060	.025	.600	58,100	+620	+620
78	42 x	41,810	57,530	22.25	57.2	.09	.046	.025	.315	53,670	+3,860	+860
79	42 x	30,790	51,650	27.25	66.4	.09	.022	.030	.308	52,804	-1,154	-1,154
80	35 x	34,440	55,680	30.50	59.5	.09	.065	.030	.425	56,850	-1,170	-1,170
81	72½ x 15	33,600	52,800	29.25	71.4	.09	.027	.035	.323	53,800	-1,000	-2,000
82	42 x	30,970	56,830	31.25	66.7	.09	.046	.035	.540	57,700	-870	-870
83	33 x 17½	36,410	58,350	28.75	65.3	.09	.030	.040	.325	54,400	+3,950	+4,450
84	60 x 16½	34,040	60,160	26.50	58.3	.09	.063	.040	.375	56,900	+3,260	+3,760
85	7½ x	38,100	60,380	27.50	64.0	.09	.039	.040	.595	58,350	+2,030	+2,030
86	78 x 15	41,180	64,410	22.50	60.8	.09	.073	.040	.563	59,730	+4,680	+3,680
87	43 x	34,660	63,080	27.50	46.8	.09	.063	.040	.525	58,850	+4,230	+4,230
88	16 x	35,330	55,040	30.75	64.4	.09	.054	.045	.505	58,650	-3,610	-3,110
89	72 x	41,450	60,970	21.25	59.2	.09	.036	.045	.525	57,950	+3,020	+2,020
90	48 x	36,360	58,190	28.00	50.7	.09	.070	.045	.550	59,900	-1,710	-1,710
91	24½ x	36,220	60,070	29.75	56.5	.09	.055	.045	.440	57,910	+2,160	+2,160
92	87½ x 17½	34,730	56,410	27.50	67.0	.09	.036	.050	.420	57,130	-720	-1,220
93	72 x	41,670	60,000	20.50	59.0	.09	.037	.055	.475	58,350	+1,650	+650
94	47 x	34,910	58,790	26.75	62.5	.09	.037	.060	.590	60,000	-1,210	-1,210
95	22½ x	35,290	60,850	23.75	60.5	.09	.051	.060	.735	62,150	-1,300	+700
96	42 x	39,060	65,100	25.00	44.6	.09	.078	.060	.400	59,850	+5,250	+5,250
97	47 x	36,730	60,350	25.00	61.5	.09	.049	.065	.505	60,200	+150	+150
98	47 x	34,950	58,940	28.00	63.8	.09	.034	.065	.585	60,250	-1,310	-1,310
99	52 x 22½	32,800	59,580	28.75	54.1	.09	.074	.065	.629	62,690	-3,110	-1,860
100	77½ x 1	34,840	58,500	20.25	61.7	.09	.060	.065	.480	60,460	-1,960	-1,960

TABLE III.—Continued.

No. of Tests.	Size of Plates, Inches.	Elastic Limit.	Ultimate Strength.	Per Ct. Elong. in 8 In.	Per Ct. Reduction.	Analysis.				Estimated by Table.		Difference after Correcting for Size.
						C.	S.	P.	Mn.	Ultimate Strength.	Difference.	
101	55 x 26	35,380	60,830	27.75	53.1	.09	.045	.070	.365	58,540	+2,290	+3,790
102	24 x	39,270	59,340	29.25	51.1	.09	.068	.080	.440	61,710	-2,370	-2,370
103	72 x	38,980	64,410	22.00	51.2	.09	.069	.080	.345	60,310	+4,100	+3,100
104	72 x	35,050	64,600	22.75	55.6	.09	.074	.080	.345	60,560	+4,040	+ 40
105	60 x	36,840	55,150	26.25	54.3	.10	.075	.020	.320	55,760	- 610	- 610
106	60 x	42,200	60,410	25.25	52.6	.10	.032	.025	.570	57,450	+2,960	+2,960
107	44 x 22	34,480	57,000	28.25	60.6	.10	.028	.025	.385	55,010	+1,990	+3,240
108	60 x	33,760	57,350	25.75	53.4	.10	.064	.030	.520	59,050	-1,700	-1,700
109	33 x	32,810	61,200	27.00	52.3	.10	.079	.035	.455	59,560	+1,640	+1,640
110	35 x	34,720	57,780	27.00	62.9	.10	.044	.035	.435	57,540	+ 240	+ 240
111	25 x	33,410	54,980	28.25	56.9	.10	.056	.035	.485	58,770	-3,790	-3,790
112	65 x 15	34,530	58,490	27.00	60.4	.10	.043	.035	.500	58,300	+ 190	+ 190
113	65 x 15	37,070	60,340	26.50	54.8	.10	.050	.035	.510	58,750	+1,590	+1,590
114	72 x 14	41,890	57,230	22.25	39.5	.10	.054	.035	.363	56,958	+ 272	- 728
115	54 x	34,720	56,930	27.50	56.9	.10	.052	.035	.545	59,200	-2,270	- 770
116	43 x	33,620	55,080	26.25	62.4	.10	.031	.035	.370	55,920	- 840	- 840
117	33 x	35,850	55,740	30.00	65.2	.10	.040	.040	.363	56,758	-1,018	-1,018
118	56 x 22	35,120	59,160	26.00	50.6	.10	.054	.040	.460	58,870	+ 290	+1,540
119	14 x	38,350	59,860	21.25	54.1	.10	.044	.040	.360	56,330	+3,030	+ 30
120	35 x	31,920	59,380	26.75	58.2	.10	.044	.040	.570	59,550	- 170	+ 830
121	24 x	32,770	56,180	27.00	56.7	.10	.044	.040	.405	57,620	-1,440	- 190
122	60 x 16	34,230	57,950	27.00	65.0	.10	.032	.040	.395	56,870	+1,080	+1,580
123	45 x	35,410	58,180	26.75	66.3	.10	.037	.040	.528	58,780	- 600	- 600
124	20 x	30,190	60,860	29.50	47.9	.10	.077	.045	.630	62,300	-1,440	+ 560
125	31 x 15	32,610	60,060	26.50	48.4	.10	.066	.045	.465	60,030	+ 30	+ 30
126	51 x 20	30,000	58,580	30.75	56.3	.10	.061	.045	.445	59,530	- 950	+ 50
127	60 x 22	32,080	60,220	24.25	50.4	.10	.040	.045	.470	58,790	+1,430	+2,680
128	44 x	35,050	58,760	28.00	55.4	.10	.053	.045	.338	57,484	+1,276	+1,276
129	40 x 22	33,210	59,450	27.00	45.0	.10	.063	.045	.422	59,308	+ 142	+1,392
130	45 x	38,980	59,650	28.25	52.8	.10	.062	.045	.475	59,950	- 300	- 300
131	51 x 22	34,130	57,800	28.75	61.8	.10	.040	.045	.482	58,932	-1,132	+ 118
132	35 x	33,780	57,640	28.75	58.7	.10	.078	.050	.315	58,820	-1,180	-1,180
133	84 x	34,700	61,560	20.50	51.5	.10	.068	.050	.565	61,650	- 90	-1,090
134	65 x	35,340	57,170	24.25	61.7	.10	.046	.050	.640	61,350	-4,180	-3,180
135	48 x	36,240	63,770	25.50	52.8	.10	.071	.055	.513	61,830	+1,940	+1,940
136	44 x	32,110	58,810	26.75	52.9	.10	.063	.055	.585	62,150	-3,340	-2,090
137	78 x	35,070	60,290	19.25	64.6	.10	.030	.055	.408	58,462	+1,828	+ 828
138	48 x	37,920	64,160	22.50	55.0	.10	.041	.055	.445	59,530	+4,630	+1,630
139	22 x	36,380	58,770	27.75	61.8	.10	.041	.055	.428	59,292	- 522	- 522
140	60 x 22	33,510	61,520	30.00	51.4	.10	.047	.060	.422	60,080	+1,440	+2,690
141	34 x	35,410	60,060	27.00	51.0	.10	.077	.065	.475	62,700	-2,640	-2,640
142	23 x	35,830	64,720	21.50	51.9	.10	.047	.065	.488	61,356	+3,364	+3,364
143	53 x	35,540	67,640	24.00	43.0	.10	.068	.070	.333	60,644	+6,996	+6,996
144	52 x 14	43,890	64,170	25.00	61.1	.10	.043	.070	.405	60,570	+3,600	+3,600
145	36 x	38,580	63,260	26.25	44.3	.10	.044	.075	.440	61,610	+1,650	+1,650
146	42 x	38,740	61,250	24.00	59.5	.10	.043	.080	.483	62,602	-1,352	-1,352
147	62 x	38,620	64,820	23.00	48.6	.10	.053	.080	.485	63,120	+1,700	+1,700
148	60 x	41,050	66,910	23.75	48.8	.10	.065	.090	.425	63,950	+2,960	+2,960
149	26 x	37,250	65,830	25.00	59.1	.10	.068	.095	.380	63,930	+1,900	+1,900
150	72 x	33,880	59,830	27.25	52.1	.11	.033	.015	.440	56,010	+3,820	+2,820

TABLE III.—*Continued.*

No. of Tests.	Size of Plates, Inches.	Elastic Limit.	Ultimate Strength.	Per Ct. Elong. in 8 In.	Per Ct. Reduction.	Analysis.				Estimated by Table.		Difference after Correcting for Size.
						C.	S.	P.	Mn.	Ultimate Strength.	Difference.	
151	32 x 48	35,200	59,570	30.00	60.6	11	.048	.020	.735	60,400	- 830	- 830
152	44 x 48	35,030	56,970	27.50	51.9	11	.050	.020	.573	58,880	- 1,910	- 1,910
153	71 x 48	37,760	56,710	30.00	56.2	11	.033	.026	.378	56,308	+ 402	+ 402
154	20 x 48	30,210	58,680	23.25	68.1	11	.035	.030	.340	56,220	+ 2,460	- 540
155	36 x 48	29,880	55,010	26.50	54.5	11	.076	.030	.495	60,490	- 5,480	- 3,480
156	42 x 48	34,920	57,410	27.50	56.9	11	.066	.030	.355	58,030	- 630	- 630
157	12 x 48	32,970	52,700	29.50	63.8	11	.040	.035	.390	57,840	- 5,140	- 5,140
158	23 x 48	33,240	58,580	22.50	64.6	11	.062	.035	.410	59,240	- 660	- 660
159	20 x 48	31,760	58,410	26.75	46.8	11	.040	.040	.540	60,250	- 1,840	+ 160
160	48 x 48	36,590	60,980	24.00	50.5	11	.052	.040	.335	58,080	+ 2,900	+ 3,400
161	43 x 48	37,100	59,020	28.00	53.8	11	.063	.040	.560	61,600	- 2,580	- 2,580
162	60 x 48	36,750	64,410	26.25	55.7	11	.057	.045	.630	62,550	+ 1,860	+ 1,860
163	60 x 22 x 1/2	33,580	61,100	26.50	54.3	11	.059	.045	.525	61,600	- 500	+ 750
164	35 x 48	35,550	61,400	27.50	56.1	11	.075	.050	.393	61,288	+ 112	+ 112
165	72 x 15	34,090	59,950	23.75	61.6	11	.038	.050	.585	61,700	- 1,750	- 2,750
166	32 x 48	39,300	65,320	27.75	50.0	11	.079	.050	.340	60,620	+ 4,700	+ 4,700
167	78 x 48	36,860	55,410	27.50	55.7	11	.012	.051	.363	57,768	- 2,358	- 3,358
168	78 x 48	37,840	56,550	25.50	50.4	11	.025	.056	.552	61,380	- 4,880	- 5,880
169	54 x 48	41,320	66,120	25.50	44.9	11	.069	.060	.585	64,350	+ 1,770	- 1,770
170	59 x 20	39,210	61,830	28.75	55.2	11	.036	.060	.422	60,858	+ 972	- 1,972
171	64 x 26 x 1/2	35,350	61,450	26.00	53.2	11	.043	.065	.465	62,330	- 880	+ 620
172	78 x 17 x 1/2	32,420	61,880	26.50	49.1	11	.032	.065	.505	62,250	- 370	- 870
173	72 x 8	37,330	67,090	22.50	51.8	11	.043	.070	.545	63,650	+ 4,040	+ 3,040
174	8 x 15	35,960	67,520	22.50	46.4	11	.065	.070	.475	64,100	+ 3,420	+ 3,920
175	15 x 48	38,100	66,670	20.75	45.9	11	.067	.070	.470	64,140	+ 2,530	+ 2,530
176	36 x 48	38,980	63,710	27.00	56.2	11	.066	.070	.435	63,640	+ 70	+ 70
177	38 x 48	40,070	66,480	23.75	46.3	11	.054	.075	.428	63,492	+ 2,988	+ 2,988
178	36 x 48	34,250	65,200	25.00	53.7	11	.043	.080	.465	63,980	+ 1,240	+ 1,240
179	72 x 48	42,100	60,860	25.00	59.8	11	.070	.080	.370	63,970	- 3,110	- 7,110
180	20 x 48	34,420	63,410	25.50	56.3	11	.073	.085	.397	65,102	- 1,692	- 1,692
181	44 x 48	38,910	65,530	23.25	62.3	11	.066	.090	.555	67,200	- 1,670	- 1,670
182	38 x 12 x 1/2	43,240	72,260	25.50	41.2	11	.043	.095	.562	66,670	+ 5,590	+ 2,590
183	72 x 48	38,730	71,130	22.00	53.9	11	.062	.095	.495	66,040	+ 4,190	+ 190
184	59 x 48	30,410	55,740	30.00	58.6	12	.035	.015	.525	58,050	- 2,310	- 810
185	78 x 48	33,970	58,970	24.25	60.6	12	.047	.025	.378	57,948	+ 1,022	+ 22
186	60 x 48	32,130	60,680	25.25	56.2	12	.058	.025	.525	60,400	+ 280	+ 1,280
187	56 x 31	31,400	57,370	26.50	47.8	12	.051	.030	.410	59,240	- 1,870	+ 130
188	36 x 48	37,940	59,900	26.75	54.7	12	.041	.035	.395	59,120	+ 780	+ 780
189	50 x 20	35,340	59,880	27.00	55.7	12	.043	.035	.398	59,268	+ 612	+ 1,612
190	7 x 48	34,050	59,540	25.00	53.5	12	.060	.035	.490	61,330	- 1,790	- 1,790
191	78 x 48	36,310	61,010	25.50	64.0	12	.052	.035	.558	61,630	- 620	- 1,620
192	59 x 48	33,270	64,550	21.50	43.2	12	.079	.045	.293	60,480	+ 4,090	+ 5,090
193	54 x 48	35,620	65,960	26.00	53.8	12	.059	.050	.495	63,140	+ 2,820	+ 2,820
194	36 x 48	35,420	60,500	25.00	53.7	12	.060	.050	.563	63,980	- 3,380	- 3,380
195	66 x 48	38,380	64,720	24.00	38.0	12	.056	.055	.495	62,590	+ 2,130	+ 3,630
196	61 x 25	35,900	71,620	21.25	42.5	12	.062	.055	.510	64,050	+ 7,570	+ 9,070
197	64 x 48	35,880	64,340	25.50	47.3	12	.060	.059	.478	64,186	+ 154	+ 654
198	71 x 48	32,750	65,890	23.50	42.1	12	.050	.060	.688	65,830	+ 60	+ 60
199	64 x 48	39,600	66,800	23.50	41.4	12	.072	.065	.568	66,330	+ 470	+ 1,470
200	58 x 48	37,920	68,860	23.50	37.3	12	.077	.065	.550	66,400	+ 2,460	+ 2,460

TABLE III.—Continued.

No. of Tests.	Size of Plates, Inches.	Elastic Limit.	Ultimate Strength.	Per Ct. Elong. in 8 in.	Per Ct. Reduction.	Analysis.				Estimated by Table.		Difference after Correcting for Size.
						C.	S.	P.	Mn.	Ultimate Strength.	Difference.	
201	63½ × 1½	34,410	61,290	22.00	60.0	12	048	085	415	65,760	-4,470	-3,470
202	18½ × 1½	37,080	70,100	25.00	46.1	12	079	090	490	68,880	+1,220	+1,720
203	50 × 26	32,370	55,140	26.75	61.5	13	025	021	450	58,430	-2,290	-2,290
204	44½ × 26	37,130	66,800	23.75	47.7	13	053	025	475	60,650	+6,150	+7,650
205	55 × 31	32,580	61,520	23.00	42.6	13	047	030	500	61,300	+220	+2,220
206	42 × 31	41,670	67,590	22.50	49.1	13	050	035	448	61,502	+6,088	+6,088
207	41½ × 31	35,780	63,900	24.00	47.3	13	067	050	415	63,810	+90	-2,910
208	19½ × 31	34,910	71,500	22.50	41.0	13	075	065	508	67,330	+4,170	+4,170
209	72 × 26	36,060	73,400	18.75	42.7	13	071	070	500	67,700	+5,700	+4,700
210	72½ × 15	36,270	73,060	22.00	44.8	13	058	080	430	67,470	+5,590	+4,590
211	59½ × 31	35,650	67,530	23.00	49.5	13	041	090	625	70,050	-2,520	-1,520
212	42 × 31	36,500	71,260	23.75	44.5	13	060	095	575	71,150	+110	+110
213	40 × 18	37,530	61,800	28.00	56.7	14	068	040	350	62,750	-950	-450
214	36½ × 26	34,800	70,960	21.25	35.1	14	070	040	425	63,930	+7,030	+7,030
215	52 × 22½	35,740	64,460	28.75	53.3	14	055	040	548	64,680	-220	+1,030
216	53½ × 26	35,180	65,100	25.00	55.4	14	077	050	333	64,294	+806	+806
217	72 × 26	42,910	71,810	25.00	42.7	14	062	055	545	67,100	+4,710	+3,710
218	39½ × 26	38,760	71,660	22.25	42.3	14	077	060	510	68,200	+3,460	+460
219	56 × 25	35,060	68,640	25.00	43.2	14	035	070	455	67,130	+1,510	+3,010
220	48 × 26	32,570	61,500	26.50	57.6	14	065	085	295	67,900	-6,400	-4,900
221	60 × 26	31,820	68,190	23.75	37.3	15	065	040	450	65,300	+2,890	+3,890
222	43 × 26	38,780	67,920	24.00	41.0	15	069	040	430	65,620	+2,300	+3,800
223	66 × 26	39,850	66,220	23.75	46.7	15	042	047	421	64,794	+1,430	+1,430
224	48 × 26	31,980	60,530	28.75	52.0	15	051	060	415	67,110	-6,580	-5,080
225	71½ × 12½	42,520	72,440	20.00	44.2	15	070	080	485	71,970	+470	-3,530
226	26 × 12½	41,390	73,840	21.25	48.3	15	074	080	238	68,076	+5,764	+2,764
227	45 × 26	34,870	56,530	29.50	46.1	16	039	034	391	63,056	-6,526	-6,526
228	50½ × 26	37,540	70,280	23.75	37.7	16	055	045	537	67,320	+2,960	+2,960
229	41½ × 26	39,590	66,270	25.00	47.7	16	063	050	403	66,842	-572	-572
230	53 × 26	40,580	73,770	18.75	30.7	16	073	061	538	70,630	+3,140	+140
231	62½ × 26½	35,970	70,920	22.50	38.9	16	078	075	535	72,950	-2,030	-530
232	58½ × 26½	37,720	71,460	22.50	35.8	16	063	080	585	73,450	-1,990	-490
233	62½ × 26½	38,310	71,320	23.50	38.1	17	077	085	520	75,050	-3,730	-2,230
234	60 × 26	42,100	67,310	22.50	37.9	18	066	025	580	66,900	+410	+410
235	81 × 12	39,200	72,760	21.50	53.2	18	068	030	425	66,000	+6,760	+2,760
236	45 × 26	43,130	71,710	23.50	47.6	18	053	054	652	71,320	+390	+390
237	48 × 26	38,690	68,360	22.50	42.4	18	050	065	630	72,600	-4,240	-2,240

TABLE IV.—Carbon, both Mills.

	°6, °7, °8, and °9 C.				°10, °11, and °12 C.				°13, °14, °15, °16, °17, and °18 C.				All Carbons.			
	Under 1 in. 1 1/2 in.	1 in. 1 1/2 in.	1 in. to 1 1/2 in.	1 in. 1 1/2 in.	Under 1 in. 1 1/2 in.	1 in. 1 1/2 in.	1 in. to 1 1/2 in.	1 in. 1 1/2 in.	Under 1 in. 1 1/2 in.	1 in. 1 1/2 in.	1 in. to 1 1/2 in.	1 in. 1 1/2 in.	Under 1 in. 1 1/2 in.	1 in. 1 1/2 in.	1 in. to 1 1/2 in.	All Sizes.
+ over 5,000 . . .	2	2	0	1	1	3	0	1	2	4	0	2	5	9	0	18
+ 4 to 5,000 . . .	2	4	0	0	5	3	1	1	0	2	0	0	7	9	1	18
+ 3,, 4,000 . . .	2	8	3	0	1	7	1	1	2	0	1	0	5	15	5	26
+ 2,, 3,000 . . .	1	8	2	3	1	10	1	3	0	4	1	1	2	22	4	35
+ 1,, 2,000 . . .	2	11	4	3	0	19	5	6	0	2	1	1	2	32	10	54
Within ± 1,000 . . .	1	21	12	9	0	26	17	6	2	6	4	2	3	53	33	105
- 1 to 2,000 . . .	0	14	4	10	0	11	5	6	0	0	1	2	0	25	10	53
- 2,, 3,000 . . .	0	12	6	4	0	5	2	4	0	1	2	5	0	18	10	41
- 3,, 4,000 . . .	0	6	5	0	1	4	6	1	0	1	1	3	1	11	12	28
- 4,, 5,000 . . .	0	2	2	2	1	3	3	4	0	0	0	1	1	5	5	18
- over 5,000 . . .	0	0	0	3	0	2	1	2	0	1	0	2	0	3	1	11
Total + . . .	58					70				23			21	87	20	151
Total - . . .	70					61				20			2	62	38	151
Difference = . . .	-12					+ 9				+ 3			+19	+25	-18	0
Per cent. within 5,000 . . .	95.3					94.4				80.7			80.8	94.1	93.9	93.9

TABLE IV. A.—Carbon, corrected for Size, both Mills.

	‘06, ‘07, ‘08, and ‘09 C.				‘10, ‘11, and ‘12 C.				‘13, ‘14, ‘15, ‘16, ‘17, and ‘18 C.				All Carbons.			
	Under ½ in.	½ in. and ¾ in.	¾ in. and 1 in.	1 in. to 1 ¼ in.	Under ½ in.	½ in. and ¾ in.	¾ in. and 1 in.	1 in. to 1 ¼ in.	Under ½ in.	½ in. and ¾ in.	¾ in. and 1 in.	1 in. to 1 ¼ in.	Under ½ in.	½ in. and ¾ in.	¾ in. and 1 in.	1 in. to 1 ¼ in.
+ over 5,000 . . .	0	2	0	1	0	3	1	3	0	2	0	2	0	7	1	6
+ 4 to 5,000 . . .	0	3	3	1	0	2	1	0	0	3	1	0	0	8	5	1
+ 3 „ 4,000 . . .	1	7	2	4	0	9	2	7	0	2	1	2	1	18	5	13
+ 2 „ 3,000 . . .	1	8	4	5	1	9	4	3	2	3	1	1	4	20	9	9
+ 1 „ 2,000 . . .	1	11	8	3	4	17	9	4	0	2	3	1	5	30	20	8
Within ± 1,000 . . .	3	20	7	14	3	26	13	11	2	6	2	6	8	52	22	31
- 1 to 2,000 . . .	3	18	7	2	0	12	2	0	0	0	2	3	3	30	11	5
- 2 „ 3,000 . . .	0	10	5	1	0	5	6	5	1	2	1	2	1	17	12	8
- 3 „ 4,000 . . .	1	8	2	3	0	5	3	2	1	0	0	0	2	13	5	5
- 4 „ 5,000 . . .	0	0	0	1	0	3	1	0	0	0	0	1	0	3	1	2
- over 5,000 . . .	0	1	0	0	2	2	0	0	0	1	0	1	2	4	0	1
Total + . . .	65				79				26				83			
Total - . . .	62				48				15				67			
Difference = . . .	+ 3				+ 31				+ 11				+ 2			
Per cent. within 5,000	97.7				93.9				89.5				92.3			
													94.6			
													98.9			
													92.1			
													+ 16			
													+ 45			
													94.9			

TABLE V.—*Sulphur, both Mills.*

	Under '02, '02, '03 S.				'04, '05 S.				'06, '07 S.				All Sulphurs.				
	Under		1/2 in. and to 1 in.		Under		1/2 in. and to 1 in.		Under		1/2 in. and to 1 in.		Under		1/2 in. and to 1 in.		
	1/2 in.	1/2 in. and to 1 in.	1/2 in.	1/2 in. and to 1 in.	1/2 in.	1/2 in. and to 1 in.	1/2 in.	1/2 in. and to 1 in.	1/2 in.	1/2 in. and to 1 in.	1/2 in.	1/2 in. and to 1 in.	1/2 in.	1/2 in. and to 1 in.	1/2 in.	1/2 in. and to 1 in.	
+ over 5,000 . . .	1	1	0	0	1	3	0	2	3	5	0	2	5	9	0	4	18
+ 4 to 5,000 . . .	0	1	0	0	1	1	0	1	6	7	1	0	7	9	1	1	18
+ 3 ,, 4,000 . . .	0	6	1	0	3	4	3	0	2	5	1	1	5	15	5	1	26
+ 2 ,, 3,000 . . .	1	3	2	1	0	13	1	4	1	6	1	2	2	22	4	7	35
+ 1 ,, 2,000 . . .	1	7	2	3	1	14	6	4	0	11	2	3	2	32	10	10	54
Within \pm 1,000 . . .	0	12	5	5	0	20	19	11	3	21	9	1	3	53	33	17	106
- 1 to 2,000 . . .	0	8	3	3	0	7	6	11	0	10	1	4	0	25	10	18	53
- 2 ,, 3,000 . . .	0	3	3	5	0	7	4	6	0	8	3	2	0	18	10	13	41
- 3 ,, 4,000 . . .	0	1	0	0	0	6	6	3	1	4	6	1	1	11	12	4	28
- 4 ,, 5,000 . . .	0	1	0	0	1	1	4	5	0	3	1	2	1	5	5	7	18
- over 5,000 . . .	0	1	0	0	0	1	0	4	0	1	1	3	0	3	1	7	11
Total + . . .	30				62				59				21	87	20	23	151
Total - . . .	28				72				51				2	62	38	49	151
Difference = . . .	+ 2				- 10				+ 8				+ 19	+ 25	- 18	- 26	0
Percent. within 5,000	96.3				94.0				89.6				80.8	94.1	98.9	87.6	92.9

TABLE V.A.—Sulphur, corrected for Size, both Mills.

	Under .02, .03, .05 S.						.04, .05 S.						.06, .07 S.						All Sulphurs.					
	Under .02			.03			.05			Under .04			.05			Under .06			.07			All Sizes		
	Under 1/8 in.	1/8 in. and 1/16 in.	1/8 in. to 1/16 in.	Under 1/8 in.	1/8 in. and 1/16 in.	1/8 in. to 1/16 in.	Under 1/8 in.	1/8 in. and 1/16 in.	1/8 in. to 1/16 in.	Under 1/8 in.	1/8 in. and 1/16 in.	1/8 in. to 1/16 in.	Under 1/8 in.	1/8 in. and 1/16 in.	1/8 in. to 1/16 in.	Under 1/8 in.	1/8 in. and 1/16 in.	1/8 in. to 1/16 in.	Under 1/8 in.	1/8 in. and 1/16 in.	1/8 in. to 1/16 in.	Under 1/8 in.	1/8 in. and 1/16 in.	1/8 in. to 1/16 in.
+ over 5,000 . . .	0	1	0	0	0	2	0	3	0	0	4	1	3	0	7	1	6	14						
+ 4 to 5,000 . . .	0	2	1	0	0	1	3	0	0	0	5	1	1	0	8	5	1	14						
+ 3 ,, 4,000 . . .	1	3	3	4	0	6	1	7	0	1	9	1	2	1	18	5	13	37						
+ 2 ,, 3,000 . . .	0	4	1	1	1	11	6	6	3	5	2	2	2	4	20	9	9	42						
+ 1 ,, 2,000 . . .	0	5	2	2	1	14	12	5	4	11	6	1	5	30	20	8	63							
Within ± 1,000 . . .	1	12	6	9	3	20	13	16	4	20	3	6	8	52	22	31	113							
- 1 to 2,000 . . .	1	10	3	1	1	9	3	4	1	11	5	0	3	30	11	5	49							
- 2 ,, 3,000 . . .	0	3	0	0	0	5	7	5	1	9	5	3	1	17	12	8	38							
- 3 ,, 4,000 . . .	0	2	0	0	0	7	4	4	2	4	1	1	2	13	5	5	25							
- 4 ,, 5,000 . . .	0	0	0	0	0	1	0	0	0	2	1	2	0	3	1	2	6							
- over 5,000 . . .	0	2	0	0	1	1	0	1	1	1	0	0	2	4	0	1	7							
Total + . . .	30					79							61			10	83	40	37	170				
Total - . . .	22					53							50			8	67	29	21	125				
Difference = . . .	+ 8					+ 26							+ 11			+ 2	+ 16	+ 11	+ 16	+ 45				
Percent. within 5,000	96.3					95.7							93.1			92.3	94.6	98.9	92.1	94.9				

TABLE V.—Sulphur, both Mills.

	Under '02, '02, '03 S.				'04, '05 S.				'06, '07 S.				All Sulphurs.				
	Under ½ in.	½ in. and to 1 in.	½ in. and to 1 in.	½ in. and to 1 in.	Under ½ in.	½ in. and to 1 in.	½ in. and to 1 in.	½ in. and to 1 in.	Under ½ in.	½ in. and to 1 in.	½ in. and to 1 in.	Under ½ in.	½ in. and to 1 in.	½ in. and to 1 in.	All Sizes.		
+ over 5,000 . . .	1	1	0	0	1	3	0	2	3	5	0	2	5	9	0	4	18
+ 4 to 5,000 . . .	0	1	0	0	1	1	0	1	6	7	1	0	7	9	1	1	18
+ 3 „ 4,000 . . .	0	6	1	0	3	4	3	0	2	5	1	1	5	15	5	1	26
+ 2 „ 3,000 . . .	1	3	2	1	0	13	1	4	1	6	1	2	2	22	4	7	35
+ 1 „ 2,000 . . .	1	7	2	3	1	14	6	4	0	11	2	3	2	32	10	10	54
Within ± 1,000 . . .	0	12	5	5	0	20	19	11	3	21	9	1	3	53	33	17	106
- 1 to 2,000 . . .	0	8	3	3	0	7	6	11	0	10	1	4	0	25	10	18	53
- 2 „ 3,000 . . .	0	3	3	5	0	7	4	6	0	8	3	2	0	18	10	13	41
- 3 „ 4,000 . . .	0	1	0	0	0	6	6	3	1	4	6	1	1	11	12	4	28
- 4 „ 5,000 . . .	0	1	0	0	1	1	4	5	0	3	1	2	1	5	5	7	18
- over 5,000 . . .	0	1	0	0	0	1	0	4	0	1	1	3	0	3	1	7	11
Total + . . .	30				62				59				21				151
Total - . . .	28				72				51				2				151
Difference = . . .	+ 2				- 10				+ 8				+ 19				0
Per cent. within 5,000	96.3				94.0				89.6				80.3				92.9

TABLE V.A.—Sulphur, corrected for Size, both Mills.

	Under .02, .03, .06 S.				.04, .05 S.				.06, .07 S.				All Sulphurs.									
	Under ½ in.	¾ in. 1 ⅞ in.	¾ in. to 1 in.	Under ¾ in.	¾ in. and ¾ in.	¾ in. and ¾ in.	¾ in. and ¾ in.	¾ in. and ¾ in.	Under ¾ in.	¾ in. and ¾ in.	¾ in. and ¾ in.	Under ¾ in.	¾ in. and ¾ in.	¾ in. and ¾ in.	¾ in. and ¾ in.	¾ in. and ¾ in.	¾ in. and ¾ in.	All Sizes.				
+ over 5,000 . . .	0	1	0	0	0	2	0	3	0	4	1	3	0	7	1	6	14					
+ 4 to 5,000 . . .	0	2	1	0	0	1	3	0	0	5	1	1	0	8	5	1	14					
+ 3 ,, 4,000 . . .	1	3	3	4	0	6	1	7	0	9	1	2	1	18	5	13	37					
+ 2 ,, 3,000 . . .	0	4	1	1	1	11	6	6	3	5	2	2	4	20	9	9	42					
+ 1 ,, 2,000 . . .	0	5	2	2	1	14	12	5	4	11	6	1	5	30	20	8	63					
Within ± 1,000 . . .	1	12	6	9	3	20	13	16	4	20	3	6	8	52	22	31	113					
- 1 to 2,000 . . .	1	10	3	1	1	9	3	4	1	11	5	0	3	30	11	5	49					
- 2 ,, 3,000 . . .	0	3	0	0	0	5	7	5	1	9	5	3	1	17	12	8	38					
- 3 ,, 4,000 . . .	0	2	0	0	0	7	4	4	2	4	1	1	2	13	5	5	25					
- 4 ,, 5,000 . . .	0	0	0	0	0	1	0	0	0	2	1	2	0	3	1	2	6					
- over 5,000 . . .	0	2	0	0	1	1	0	1	1	1	0	0	2	4	0	1	7					
Total + . . .	30				79				61				83				37				170	
Total - . . .	22				53				50				67				29				21	125
Difference = . . .	+ 8				+ 26				+ 11				+ 16				+ 11				+ 16	+ 45
Percent. within 5,000	96.3				95.7				93.1				94.6				98.9				92.1	94.9

TABLE VI.—Phosphorus, both Mills.

	Under -02, -02, -03 P.				-04, -05, -06 P.				-07, -08, -09 P.				All Phosphorus.				
	Under § in.	§ in. and 1/16 in.	1/16 in. to 1/8 in.	1/8 in. to 1 in.	Under § in.	§ in. and 1/16 in.	1/16 in. to 1/8 in.	1/8 in. to 1 in.	Under § in.	§ in. and 1/16 in.	1/16 in. to 1/8 in.	1/8 in. to 1 in.	Under § in.	§ in. and 1/16 in.	1/16 in. to 1/8 in.	All Sizes.	
+ over 5,000 . . .	1	2	0	2	1	2	0	1	3	5	0	1	5	9	0	4	18
+ 1 to 2,000 . . .	0	0	0	1	3	6	1	0	4	3	0	0	7	9	1	1	18
+ 2 ,, 3,000 . . .	2	5	2	1	3	8	3	0	0	2	0	0	5	15	5	1	26
+ 3 ,, 4,000 . . .	1	7	2	1	1	9	1	5	0	6	1	1	2	22	4	7	35
+ 4 ,, 5,000 . . .	0	6	2	3	2	18	7	4	0	8	1	3	2	32	10	10	54
Within ± 1,000 . . .	1	24	15	9	1	24	14	7	1	5	4	1	3	53	33	17	106
- 1 to 2,000 . . .	0	13	4	7	0	8	5	9	0	4	1	2	0	25	10	18	53
- 2 ,, 3,000 . . .	0	9	7	5	0	6	2	7	0	3	1	1	0	18	10	13	41
- 3 ,, 4,000 . . .	0	4	5	0	0	7	6	3	1	0	1	1	1	11	12	4	28
- 4 ,, 5,000 . . .	0	2	1	2	1	2	3	3	0	1	1	2	1	5	5	7	18
- over 5,000 . . .	0	2	0	3	0	1	1	3	0	0	0	1	0	3	1	7	11
Total + . . .	38				75				38				21	87	20	23	151
Total - . . .	64				67				20				2	62	38	49	151
Difference = . . .	- 26				+ 8				+ 18				+ 19	+ 25	- 18	- 26	0
Per cent. within 5,000	98.4				95.2				85.5				80.8	94.1	98.9	87.6	92.9

TABLE VI.A.—Phosphorus, corrected for Size, both Mills.

	Under '04, '02, '03 P.				'04, '05, '06 P.				'07, '08, '09 P.				All Phosphorus.				
	Under # in. 1 in.	# in. and to 1 in. 1 in.	# in. and to 1 in. 1 in.	# in. and to 1 in. 1 in.	Under # in. 1 in.	# in. and to 1 in. 1 in.	# in. and to 1 in. 1 in.	# in. and to 1 in. 1 in.	Under # in. 1 in.	# in. and to 1 in. 1 in.	# in. and to 1 in. 1 in.	# in. and to 1 in. 1 in.	Under # in. 1 in.	# in. and to 1 in. 1 in.	# in. and to 1 in. 1 in.	# in. and to 1 in. 1 in.	All 8 in.
+ over 5,000 . . .	0	2	0	4	0	2	1	1	0	3	0	1	0	7	1	6	14
+ 4 to 5,000 . . .	0	0	2	0	0	5	3	1	0	3	0	0	0	8	5	1	14
+ 3 ,, 4,000 . . .	0	3	3	2	1	10	1	8	0	5	1	3	1	18	5	13	37
+ 2 ,, 3,000 . . .	1	7	1	5	0	8	7	3	3	5	1	1	4	20	9	9	42
+ 1 ,, 2,000 . . .	0	7	9	4	3	15	9	3	2	8	2	1	5	30	20	8	63
Within \pm 1,000 . . .	3	22	10	13	3	25	9	15	2	5	3	3	8	52	22	31	113
- 1 to 2,000 . . .	0	16	6	1	3	10	4	4	0	4	1	0	3	30	11	5	49
- 2 ,, 3,000 . . .	0	8	6	1	1	6	5	4	0	3	1	3	1	17	12	8	38
- 3 ,, 4,000 . . .	1	6	1	3	0	7	3	2	1	0	1	0	2	13	5	5	25
- 4 ,, 5,000 . . .	0	0	0	1	0	2	1	0	0	1	0	1	0	3	1	2	6
- over 5,000 . . .	0	3	0	0	1	1	0	1	1	0	0	0	2	4	0	1	7
Total + . . .	50				81				39				10				
Total - . . .	53				55				17				8				
Difference = . . .	- 3				+ 26				+ 22				+ 2				
Per cent. within 5,000	94.0				96.3				92.8				92.3				

TABLE VII.—*Manganese, both Mills.*

	Under 20 to 40 Mn.				40 to 55 Mn.				55 to 75 Mn.				All Manganese.					
	Under ½ in. to 1 in.	½ in. and to 1 in.	1 in. and to 1 in.	1 in. and to 1 in.	Under ½ in. to 1 in.	½ in. and to 1 in.	1 in. and to 1 in.	1 in. and to 1 in.	Under ½ in. to 1 in.	½ in. and to 1 in.	1 in. and to 1 in.	1 in. and to 1 in.	Under ½ in. to 1 in.	½ in. and to 1 in.	1 in. and to 1 in.	Under ½ in. to 1 in.	½ in. and to 1 in.	1 in. and to 1 in.
+ over 5,000 . . .	2	2	0	2	2	2	6	0	2	1	1	0	0	5	9	0	4	18
+ 4 to 5,000 . . .	2	2	1	1	4	5	0	0	0	1	2	0	0	7	9	1	1	18
+ 3 „ 4,000 . . .	3	6	2	0	2	9	2	1	0	0	0	1	0	5	15	5	1	26
+ 2 „ 3,000 . . .	2	3	2	3	0	11	2	2	2	0	8	0	2	2	22	4	7	35
+ 1 „ 2,000 . . .	2	9	4	6	0	19	5	2	2	0	4	1	2	2	32	10	10	54
Within ± 1,000 . . .	1	20	9	9	2	24	16	7	7	0	9	8	1	3	53	33	17	106
- 1 to 2,000 . . .	0	10	0	9	0	8	9	6	0	0	7	1	3	0	25	10	18	53
- 2 „ 3,000 . . .	0	7	2	5	0	8	6	6	0	3	3	2	2	0	18	10	13	41
- 3 „ 4,000 . . .	1	1	3	1	0	7	6	2	0	0	3	3	1	1	11	12	4	28
- 4 „ 5,000 . . .	0	2	1	2	0	0	2	4	1	1	3	2	1	1	5	5	7	18
- over 5,000 . . .	0	2	0	2	0	0	0	4	0	0	1	1	1	0	3	1	7	11
Total + . . .	54				74				23					21	87	20	23	151
Total - . . .	48				68				35					2	62	38	49	151
Difference = . . .	+ 6				+ 6				- 12					+ 19	+ 25	- 18	- 26	0
Per cent. within 5,000 . . .	92.9				92.7				93.4					80.8	94.1	98.9	87.6	92.9

TABLE VII.A.—Manganese, corrected for Size, both Mills.

	Under .20 to .40 Mn.						.40 to .55 Mn.						.55 to .75 Mn.						All Manganese.					
	Under .20 to .40 Mn.			.40 to .55 Mn.			.40 to .55 Mn.			.55 to .75 Mn.			.55 to .75 Mn.			All Manganese.			All Manganese.			All Manganese.		
	Under .20 to .40 Mn.	Under .20 to .40 Mn.	Under .20 to .40 Mn.	Under .20 to .40 Mn.	Under .20 to .40 Mn.	Under .20 to .40 Mn.	Under .20 to .40 Mn.	Under .20 to .40 Mn.	Under .20 to .40 Mn.	Under .20 to .40 Mn.	Under .20 to .40 Mn.	Under .20 to .40 Mn.	Under .20 to .40 Mn.	Under .20 to .40 Mn.	Under .20 to .40 Mn.	Under .20 to .40 Mn.	Under .20 to .40 Mn.	Under .20 to .40 Mn.	Under .20 to .40 Mn.	Under .20 to .40 Mn.	Under .20 to .40 Mn.	Under .20 to .40 Mn.	Under .20 to .40 Mn.	Under .20 to .40 Mn.
+ over 5,000 . . .	0	2	1	3	0	4	0	0	3	0	1	0	0	0	7	1	6	14	0	0	0	0	0	0
+ 4 to 5,000 . . .	0	2	2	1	0	5	2	0	0	0	1	1	0	0	8	5	1	14	0	0	0	0	0	0
+ 3 ,, 4,000 . . .	0	6	3	7	1	10	2	4	4	0	2	0	2	1	18	5	13	37	0	0	0	0	0	0
+ 2 ,, 3,000 . . .	2	3	3	5	1	10	5	1	1	1	7	1	3	4	20	9	9	42	2	2	2	2	2	2
+ 1 ,, 2,000 . . .	1	7	6	4	3	19	10	4	4	1	4	4	0	5	30	20	8	63	1	1	1	1	1	1
Within $\pm 1,000$. . .	5	20	3	14	3	25	14	12	12	0	7	5	5	8	52	22	31	113	5	5	5	5	5	5
- 1 to 2,000 . . .	3	12	1	2	0	9	7	3	3	0	9	3	0	3	30	11	5	49	3	3	3	3	3	3
- 2 ,, 3,000 . . .	0	5	4	2	1	8	6	4	4	0	4	2	2	1	17	12	8	38	0	0	0	0	0	0
- 3 ,, 4,000 . . .	1	3	1	1	1	7	2	3	3	0	3	2	1	2	13	5	5	25	1	1	1	1	1	1
- 4 ,, 5,000 . . .	0	2	0	1	0	0	0	1	1	0	1	1	0	0	3	1	2	6	0	0	0	0	0	0
- over 5,000 . . .	1	2	0	0	0	0	0	1	1	1	2	0	0	2	4	0	1	7	2	2	2	2	2	2
Total + . . .	58	58	58	84	84	84	84	84	84	84	84	84	84	84	84	84	84	84	84	84	84	84	84	84
Total - . . .	41	41	41	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53
Difference = . . .	17	17	17	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31
Per cent. within 5,000	98.6	98.6	98.6	90.6	90.6	90.6	90.6	90.6	90.6	90.6	90.6	90.6	90.6	90.6	90.6	90.6	90.6	90.6	90.6	90.6	90.6	90.6	90.6	90.6

TABLE VIII.—*Estimated Ultimate Strengths, both Mills.*

	48 to 54,000.				54 to 62,000.				62 to 70,000.				Over 70,000.				All Ultimate Strengths.			
	Under 1/2 in. 1/4 in.	1/2 in. and to 3/4 in.	3/4 in. 1 in.	1 in. and to 1 1/4 in.	Under 1/2 in. 1/4 in.	1/2 in. and to 3/4 in.	3/4 in. 1 in.	1 in. and to 1 1/4 in.	Under 1/2 in. 1/4 in.	1/2 in. and to 3/4 in.	3/4 in. 1 in.	1 in. and to 1 1/4 in.	Under 1/2 in. 1/4 in.	1/2 in. and to 3/4 in.	3/4 in. 1 in.	1 in. and to 1 1/4 in.	Under 1/2 in. 1/4 in.	1/2 in. and to 3/4 in.	3/4 in. 1 in.	1 in. and to 1 1/4 in.
+ over 5,000	0	0	0	0	2	5	0	3	3	4	0	1	0	0	0	0	5	9	0	18
+ 4 to 5,000	0	0	0	0	4	6	1	1	3	3	0	0	0	0	0	0	7	9	1	18
+ 3 ,, 4,000	1	4	1	0	2	8	3	1	1	3	1	0	1	0	0	0	5	15	5	26
+ 2 ,, 3,000	0	2	2	0	2	9	0	4	0	10	2	3	0	1	0	0	2	22	4	35
+ 1 ,, 2,000	0	2	1	1	2	19	7	6	0	10	1	3	0	1	1	0	2	32	10	54
Within ± 1,000	1	9	5	6	0	32	20	9	1	10	7	2	1	2	1	0	3	53	33	106
- 1 to 2,000	0	6	0	5	0	15	9	9	0	4	1	3	0	0	0	1	0	25	10	53
- 2 ,, 3,000	0	5	4	0	0	10	4	8	0	3	1	4	0	0	1	1	0	18	10	41
- 3 ,, 4,000	0	1	2	0	0	7	4	1	1	3	6	2	0	0	0	1	1	11	12	28
- 4 ,, 5,000	0	0	0	0	0	5	3	4	1	0	2	2	0	0	0	1	1	5	5	18
- over 5,000	0	0	0	0	0	1	0	4	0	2	1	3	0	0	0	0	0	3	1	11
Total +	14					85				48			4				21	87	20	151
Total -	23					84				39			5				2	62	38	151
Difference =	- 9					+ 1				+ 9			- 1				+ 19	+ 25	- 18	0
Per cent. within 5,000	100.0					93.5				86.9			100.0				80.8	94.1	98.9	87.6

TABLE VIII.A.—*Estimated Ultimate Strengths, corrected for Size, both Mills.*

	46 to 54,000.			54 to 62,000.			62 to 70,000.			Over 70,000.			All Ultimate Strengths.				
	Under § in.	§ in. and to § in.	§ in. 1 in.	Under § in.	§ in. and to § in.	§ in. 1 in.	Under § in.	§ in. and to § in.	§ in. 1 in.	Under § in.	§ in. and to § in.	§ in. 1 in.	Under § in.	§ in. and to § in.	§ in. 1 in.	§ in. and to § in.	All Spec.
+ over 5,000 . . .	0	0	0	0	5	1	0	0	2	0	1	0	0	0	7	1	14
+ 4 to 5,000 . . .	0	0	1	0	5	3	1	0	3	1	0	0	0	0	8	5	14
+ 3 „ 4,000 . . .	0	3	2	1	8	1	7	0	7	2	5	0	0	1	18	5	37
+ 2 „ 3,000 . . .	0	2	1	1	9	6	7	3	8	1	1	0	1	0	20	9	42
+ 1 „ 2,000 . . .	0	3	4	3	16	11	4	2	10	4	1	0	1	0	30	20	63
Within ± 1,000 . . .	1	7	1	7	33	17	15	2	10	4	7	1	2	0	52	22	113
- 1 to 2,000 . . .	0	8	4	0	3	18	4	2	4	2	3	0	0	1	30	11	49
- 2 „ 3,000 . . .	0	4	2	0	0	9	5	4	1	4	5	2	0	0	17	12	38
- 3 „ 4,000 . . .	1	2	0	0	0	9	3	4	0	2	2	1	1	0	2	13	25
- 4 „ 5,000 . . .	0	0	0	0	2	0	1	0	1	1	1	0	0	0	3	1	6
- over 5,000 . . .	0	0	0	0	3	0	0	2	1	0	1	0	0	0	4	0	7
Total + . . .	21			94					51			4			83	40	170
Total - . . .	21			67					33			4			67	29	125
Difference = . . .	0			+ 27					+ 18			0			+ 16	+ 11	+ 45
Per cent. within 5,000 . . .	100.0			93.9					93.4			100.0			92.3	94.6	92.1
																	94.9

TABLE IX.—*Actual Ultimate Strength, both Mills.*

	46 to 54,000.				54 to 62,000.				62 to 70,000.				Over 70,000.				All Ultimate Strengths.				
	Under § in.	§ in. and to 1 in.	§ in. to 1 in.	§ in. to 1 in.	Under § in.	§ in. and to 1 in.	§ in. to 1 in.	§ in. to 1 in.	Under § in.	§ in. and to 1 in.	§ in. to 1 in.	§ in. to 1 in.	Under § in.	§ in. and to 1 in.	§ in. to 1 in.	§ in. to 1 in.	Under § in.	§ in. and to 1 in.	§ in. to 1 in.	§ in. to 1 in.	All to Stee.
+ over 5,000 . . .	0	0	0	0	0	1	0	0	2	4	0	3	3	4	0	1	5	9	0	4	18
+ 4 to 5,000 . . .	0	0	0	0	0	0	0	1	4	7	1	0	3	2	0	0	7	9	1	1	18
+ 3 „ 4,000 . . .	0	1	0	0	3	8	1	0	0	6	3	1	2	0	0	0	5	15	5	1	26
+ 2 „ 3,000 . . .	0	0	2	0	2	10	0	3	0	8	2	4	0	4	0	0	2	22	4	7	35
+ 1 „ 2,000 . . .	0	1	0	1	2	15	8	6	0	14	1	2	0	2	1	1	2	32	10	10	54
Within ± 1,000 . . .	1	10	5	6	0	33	20	10	1	8	7	1	1	2	1	0	3	53	33	17	106
- 1 to 2,000 . . .	0	8	1	6	0	14	9	11	0	3	0	0	0	0	0	1	0	25	10	18	53
- 2 „ 3,000 . . .	0	9	5	3	0	9	3	8	0	0	2	1	0	0	0	1	0	18	10	13	41
- 3 „ 4,000 . . .	0	6	3	0	1	4	9	3	0	1	0	0	0	0	0	1	1	11	12	4	28
- 4 „ 5,000 . . .	0	2	2	1	1	3	3	4	0	0	0	2	0	0	0	0	1	5	5	7	18
- over 5,000 . . .	0	1	0	3	0	2	1	4	0	0	0	0	0	0	0	0	0	3	1	7	11
Total + . . .	6				60				62				23				21	87	20	23	151
Total - . . .	50				89				9				3				2	62	38	49	151
Difference = . . .	- 44				29				+ 53				+ 20				+ 19	+ 25	- 18	- 26	0
Per cent. within 5,000 . . .	94.9				96.2				89.8				73.3				80.8	94.1	96.9	87.6	92.9

TABLE IX.A.—Actual Ultimate Strengths, corrected for Size, both Mills.

	46 to 54,000.				54 to 62,000.				62 to 70,000.				Over 70,000.				All Ultimate Strengths.				
	Under § in. and to § in. 1 in.	§ in. 1 in. and to § in. 1 in.	§ in. 1 in. and to § in. 1 in.	§ in. 1 in. and to § in. 1 in.	Under § in. and to § in. 1 in.	§ in. 1 in. and to § in. 1 in.	§ in. 1 in. and to § in. 1 in.	§ in. 1 in. and to § in. 1 in.	Under § in. and to § in. 1 in.	§ in. 1 in. and to § in. 1 in.	§ in. 1 in. and to § in. 1 in.	§ in. 1 in. and to § in. 1 in.	Under § in. and to § in. 1 in.	§ in. 1 in. and to § in. 1 in.	§ in. 1 in. and to § in. 1 in.	Under § in. and to § in. 1 in.	§ in. 1 in. and to § in. 1 in.	§ in. 1 in. and to § in. 1 in.	Under § in. and to § in. 1 in.	§ in. 1 in. and to § in. 1 in.	All and to Sizes. § in. 1 in.
+ over 5,000	0	0	0	0	0	1	0	1	0	4	1	4	0	2	0	1	0	7	1	6	14
+ 4 to 5,000	0	0	1	0	0	1	1	1	0	4	3	0	0	3	0	0	0	8	5	1	14
+ 3 „ 4,000	0	1	2	1	0	5	1	6	1	10	2	6	0	2	0	0	1	18	5	13	37
+ 2 „ 3,000	0	0	0	1	0	10	7	7	1	7	1	0	3	3	1	1	4	20	9	9	42
+ 1 „ 2,000	0	1	4	3	0	13	11	4	3	14	4	1	2	2	1	0	5	30	20	8	63
Within ± 1,000	0	8	2	9	4	34	17	19	1	8	3	1	3	2	0	2	8	52	22	31	113
- 1 to 2,000	0	10	4	2	3	17	5	3	0	3	2	0	0	0	0	0	3	30	11	5	49
- 2 „ 3,000	0	8	4	0	0	8	8	5	1	1	0	2	0	0	0	1	1	17	12	8	38
- 3 „ 4,000	0	8	2	3	0	5	3	2	0	0	0	0	1	0	0	0	2	13	5	5	25
- 4 „ 5,000	0	0	0	1	0	3	1	1	0	0	0	0	0	0	0	0	0	3	1	2	6
- over 5,000	0	2	0	0	2	2	0	1	0	0	0	0	0	0	0	0	2	4	0	1	7
Total +	14				69				66				21				10	83	40	37	170
Total -	45				69				9				2				8	67	29	21	125
Difference =	- 31				0				+ 57				+ 19				+ 2	+ 16	+ 11	+ 16	+ 45
Per cent. within 5,000	97.4				96.7				89.8				90.0				92.3	94.6	98.9	92.1	94.9

TABLE X.—Carbon, both *Mills*.

	Sulphur.			Phosphorus.			Manganese.			Estimated Ultimates				Thickness.			Actual Ultimates.				All Tests.	
	Under .04.	.04 to .06.	.06 to .075.	Under .04.	.04 to .06.	.06 to .075.	Under .40.	.40 to .55.	.55 to .75.	46 to 54,000.	54 to 62,000.	62 to 70,000.	Over 70,000.	$\frac{1}{8}$ in. and $\frac{1}{4}$ in.	$\frac{1}{4}$ in. and $\frac{1}{2}$ in.	$\frac{1}{2}$ in. to 1 in.	46 to 54,000.	54 to 62,000.	62 to 70,000.	Over 70,000.		
Carbon '06 '07 '08 '09	1	1	3	3	2	2	3	2	0	0	5	0	0	2	2	1	0	0	0	5	0	5
" "	6	7	6	12	5	2	12	5	2	6	13	0	0	4	3	0	2	10	7	0	19	3 to 5,000
" "	13	14	7	19	11	4	19	11	4	8	26	0	0	3	6	6	4	29	1	0	34	1 " 3,000
" "	14	21	8	26	15	2	22	15	6	21	21	1	0	1	12	9	22	20	1	0	43	Within 1,000
" "	16	20	14	30	15	5	24	18	8	20	28	2	0	0	10	14	32	18	0	0	50	1 to 3,000
" "	1	10	6	9	7	1	4	9	4	3	12	2	0	0	8	7	13	4	0	0	17	3 " 5,000
" "	0	2	1	2	1	0	1	2	0	0	3	0	0	0	0	3	3	0	0	0	3	over 5,000
Carbon '10 '11 '12	1	2	2	1	1	3	1	2	2	0	2	3	0	1	3	0	0	1	1	3	5	over 5,000
" "	2	6	12	3	10	7	4	14	2	0	13	7	0	6	10	2	0	3	14	3	20	3 to 5,000
" "	6	24	15	7	25	13	12	23	16	0	23	22	0	1	29	6	0	17	26	2	45	1 " 3,000
" "	8	23	18	18	25	6	13	27	9	0	36	13	0	0	26	17	0	38	11	0	49	Within 1,000
" "	6	16	11	11	18	4	8	18	7	0	25	8	0	0	16	7	0	30	3	0	33	1 to 3,000
" "	1	13	9	5	13	5	6	9	8	0	12	11	0	2	7	10	1	21	1	0	23	3 " 5,000
" "	0	2	3	2	3	0	1	1	3	0	2	3	0	0	2	1	1	4	0	0	5	over 5,000
Carbon '13 '14 '15 '16 '17 '18	0	3	5	4	1	3	2	6	0	0	3	5	0	4	0	2	0	0	3	5	8	over 5,000
" "	0	0	5	0	5	0	1	4	0	0	0	4	1	3	2	1	0	0	1	4	5	3 to 5,000
" "	1	5	4	0	5	5	0	7	3	0	0	7	3	0	6	2	0	0	4	6	10	1 " 3,000
" "	0	6	8	5	6	3	4	7	3	0	4	6	4	2	6	4	0	5	5	4	14	Within 1,000
" "	3	5	3	4	4	3	1	7	3	0	2	6	3	0	1	3	0	6	3	2	11	1 to 3,000
" "	0	3	3	0	5	1	1	3	2	0	0	4	3	0	1	4	0	3	2	1	6	3 " 5,000
" "	1	1	1	1	1	1	2	1	0	0	0	3	0	0	1	2	0	0	0	0	3	over 5,000

TABLE X.A.—Carbon, corrected for Size, both Mills.

	Sulphur.		Phosphorus.		Manganese.		Estimated Ultimate.		Thickness.		Actual Ultimate.				All Tests.	
	Under .04.	.04 to .06.	Under .04.	.04 to .06.	Under .40.	.40 to .55.	Under 45,000.	45,000 to 52,000.	Under 70,000.	70,000 to 72,000.	Under 54,000.	54,000 to 62,000.	62,000 to 70,000.	Over 70,000.		
Carbon .06 .07 .08 .09	0	1	0	2	2	1	0	0	0	0	0	0	3	0	3	over 5,000
" "	10	6	9	10	13	5	3	7	14	0	1	10	6	0	21	3 to 5,000
" "	10	22	9	21	17	14	6	14	26	1	0	19	12	0	41	1 " 3,000
" "	15	20	9	22	18	16	6	16	26	2	0	3	20	7	44	Within ±1,000
" "	15	17	14	28	14	17	7	18	26	2	0	3	28	12	46	1 to 3,000
" "	1	9	5	9	6	9	1	3	12	0	0	1	8	2	15	3 " 5,000
" "	0	0	1	0	0	0	1	0	0	0	0	0	0	0	1	over 5,000
Carbon .10 .11 .12	1	2	4	3	2	3	1	0	5	2	0	0	3	1	7	over 5,000
" "	3	11	7	13	7	11	3	0	12	9	0	0	11	3	21	3 to 5,000
" "	5	25	21	28	14	31	12	0	28	23	0	5	26	13	51	1 " 3,000
" "	11	27	15	21	26	31	6	0	41	12	0	3	26	13	53	Within ±1,000
" "	2	12	16	9	15	14	10	0	18	12	0	0	17	8	30	1 to 3,000
" "	1	7	6	3	9	4	2	0	7	2	0	0	8	4	14	3 " 5,000
" "	1	2	1	1	2	0	2	0	2	0	0	1	3	0	4	over 5,000
Carbon .13 .14 .15 .16 .17 .18	0	2	2	3	1	3	0	0	3	1	0	0	0	3	4	over 5,000
" "	1	1	7	0	6	3	1	8	0	9	0	0	5	2	9	3 to 5,000
" "	0	9	4	4	3	8	3	0	3	6	4	2	5	4	13	1 " 3,000
" "	2	5	9	5	8	7	5	0	2	9	5	2	6	2	16	Within ±1,000
" "	1	5	5	1	8	2	3	0	1	7	3	1	2	3	11	1 to 3,000
" "	0	0	2	0	1	1	0	0	0	1	0	0	0	1	2	3 " 5,000
" "	1	1	0	1	1	1	0	0	0	2	0	0	0	0	2	over 5,000

TABLE XI.—Sulphur, both *Mille*.

	Carbon.				Phosphorus.				Manganese.				Estimated Ultimates.				Thickness.				Actual Ultimates.				All Tests.			
	.06 to .08.	.10 to .12.	.18 to .20.	Under .04.	.04 to .069.	.07 to .099.	Under .40.	.40 to .449.	.45 to .55.	56 to 70,000.	62 to 70,000.	72 to 82,000.	84 to 92,000.	94 to 100,000.	Under 1 in.	1 in. and 1 1/2 in.	1 1/2 in. and 2 in.	2 in. and 3 in.	3 in. and 4 in.	4 in. and 5 in.	5 in. and 6 in.	6 in. and 7 in.	7 in. and 8 in.	8 in. and 9 in.			9 in. and 10 in.	Over 10 in.
Sulphur under .04	1	1	0	1	1	0	0	2	0	0	2	0	0	1	1	0	0	0	0	1	1	0	0	0	2	+ over 5,000		
	6	2	0	3	5	0	3	3	2	2	6	0	0	7	1	0	7	1	0	1	5	2	0	8	+ 3 to 5,000			
	13	6	1	9	10	1	11	5	4	6	13	1	0	2	10	4	4	4	4	3	16	1	0	20	+ 1 " 3,000			
	14	8	0	11	9	2	13	9	0	10	9	3	0	0	12	5	5	11	9	2	0	22	Within ±1,000					
Sulphur .04 to .069	16	6	3	13	11	1	10	11	4	10	13	2	0	0	11	6	8	12	12	1	0	0	0	25	- 1 to 3,000			
	1	1	0	1	1	0	0	1	1	1	1	0	0	0	0	0	0	0	1	1	0	0	2	- 3 " 5,000				
	0	0	1	1	0	0	1	0	0	0	0	1	0	0	1	0	0	0	0	0	1	0	0	1	- over 5,000			
	1	2	3	2	0	4	1	3	2	0	3	3	0	1	3	0	2	0	0	0	3	3	6	6	+ over 5,000			
Sulphur .06 to .079	7	6	0	7	4	2	7	6	0	4	8	1	0	4	5	3	1	1	7	5	0	13	0	13	+ 3 to 5,000			
	14	24	5	9	23	11	15	21	7	2	25	14	2	1	27	7	8	1	21	17	4	43	0	43	+ 1 " 3,000			
	21	23	6	24	24	2	15	25	10	7	35	6	2	0	20	19	11	7	36	5	2	50	2	50	Within ±1,000			
	20	16	5	23	14	4	18	17	6	8	25	7	1	0	14	10	17	15	25	1	0	41	0	41	- 1 to 3,000			
Sulphur .079 to .09	10	13	3	6	16	4	5	15	6	1	15	9	1	1	7	10	8	8	17	1	0	26	0	26	- 3 " 5,000			
	2	2	1	2	3	0	2	2	1	0	3	2	0	0	1	0	4	3	2	0	0	5	0	5	- over 5,000			
	3	2	5	2	3	5	5	5	0	0	5	5	0	3	5	0	2	0	0	5	5	10	5	10	+ over 5,000			
	6	12	5	1	15	7	7	14	2	0	12	10	1	8	12	2	1	0	1	15	7	23	4	23	+ 3 to 5,000			
Sulphur .09 to .10	7	15	4	4	14	8	5	15	6	0	11	14	1	1	17	3	5	0	9	13	4	26	0	26	+ 1 " 3,000			
	8	18	8	14	13	7	11	15	8	4	17	11	2	3	21	9	1	4	18	10	2	34	2	34	Within ±1,000			
	14	11	3	9	12	7	5	15	8	2	17	7	2	0	18	4	6	5	17	4	2	28	0	28	- 1 to 3,000			
	6	9	3	7	8	3	6	5	7	1	8	8	1	1	7	7	3	5	10	2	1	18	0	18	- 3 " 5,000			
Sulphur .10 to .11	1	3	1	2	2	1	1	2	2	0	2	3	0	0	1	1	1	0	1	4	0	5	0	5	- over 5,000			

TABLE XI.A.—Sulphur, corrected for Size, both Mills.

	Carbon.			Phosphorus.			Manganese.			Estimated Ultimate.			Thickness.			Actual Ultimate.				All Tests.	
	.06 to .09	.10 to .12	.13 to .18	Under .04	.04 to .06	.07 to .09	Under .40	.40 to .45	.45 to .55	46 to 54	54 to 63	63 to 70,000	Over 70,000	1 in. and 1 1/2 in.	1 1/2 in. and 2 in.	2 in. and 3 in.	3 in. and 4 in.	4 in. and 5 in.	5 in. and 6 in.		
Sulphur under .04	0	1	0	1	0	0	0	1	0	0	1	0	0	0	1	0	0	0	0	1	+ over 5,000
"	10	3	0	7	6	1	8	3	3	5	8	1	0	0	5	4	4	4	0	14	+ 3 to 5,000
"	10	5	0	6	9	0	7	5	3	5	10	0	0	0	1	3	3	2	0	15	+ 1 " 3,000
"	15	11	2	12	13	3	13	14	1	8	15	5	0	1	12	6	9	10	3	28	Within ± 1,000
"	15	2	1	11	7	0	8	7	3	10	8	0	0	1	13	3	1	11	7	18	- 1 to 3,000
"	1	1	0	1	1	0	1	1	0	1	1	0	0	0	2	0	0	0	0	2	- 3 " 5,000
"	0	1	1	1	1	0	1	0	1	0	1	1	0	0	2	0	0	0	0	2	- over 5,000
Sulphur .04 to .059	1	2	2	3	0	2	2	2	1	0	4	1	0	0	2	0	3	0	1	5	+ over 5,000
"	6	11	1	3	9	6	8	8	2	2	10	6	0	0	7	4	7	1	7	18	+ 3 to 5,000
"	22	25	9	20	28	10	16	31	9	8	32	13	3	2	25	18	11	6	29	56	+ 1 " 3,000
"	20	27	5	26	25	1	20	24	8	6	37	8	1	3	20	13	16	7	41	52	Within ± 1,000
"	17	12	5	14	14	6	13	13	3	5	18	9	2	1	14	10	9	11	21	34	- 1 to 3,000
"	9	7	0	6	8	2	3	10	3	1	12	3	0	0	8	4	4	9	7	16	- 3 " 5,000
"	0	2	1	1	2	0	1	1	1	0	1	2	0	1	1	0	1	1	2	3	- over 5,000
Sulphur .06 to .079	2	4	2	2	4	2	4	4	0	0	6	2	0	0	4	1	3	0	0	8	+ over 5,000
"	5	7	7	0	14	5	5	13	1	0	8	11	0	0	14	2	3	0	2	19	+ 3 to 5,000
"	9	21	4	8	13	13	8	17	9	1	15	17	1	7	16	8	3	1	10	34	+ 1 " 3,000
"	9	15	9	10	14	9	9	16	8	2	17	10	4	4	20	8	6	2	18	33	Within ± 1,000
"	14	16	5	13	16	6	8	18	9	3	19	12	1	2	10	3	3	5	21	35	- 1 to 3,000
"	5	6	2	5	6	2	5	3	1	6	1	1	1	2	6	2	0	1	7	1	- 3 " 5,000
"	1	1	1	1	0	1	1	0	1	0	1	1	0	1	1	0	0	1	1	2	- over 5,000

TABLE XII.A.—Phosphorus, corrected for Size, both Mills.

	Carbon.				Sulphur.				Manganese.				Estimated Ultimates.				Thickness.				Actual Ultimates.				All Tests.						
	.06 to .09	.10 to .12	.13 to .18	Under .04	.04 to .06	.06 to .08	.08 to .09	Under .079	Under .40	.40 to .49	.49 to .55	.55 to .75	Under .64	.64 to .70,000	.70,000 to .63 to	Over 70,000	Under 1/8 in.	1/8 in. and 1/4 in.	1/4 in. to 1/2 in.	1/2 in. to 3/4 in.	3/4 in. to 1 in.	Over 1 in.	Under 1/8 in.	1/8 in. to 1/4 in.		1/4 in. to 1/2 in.	1/2 in. to 3/4 in.	3/4 in. to 1 in.	Over 1 in.		
Phosphorus under .04.	0	3	3	3	3	2	2	2	4	4	0	0	6	0	0	0	0	2	2	4	0	4	0	2	4	0	0	6	+ over 5,000		
	21	9	4	7	3	8	15	17	3	2	1	0	6	4	0	0	3	5	2	0	2	6	5	0	0	10	0	9	+ 3 to 5,000		
	9	4	7	6	20	8	14	16	5	14	5	0	21	0	0	0	14	10	9	0	9	9	24	0	1	34	0	1	+ 1 " 3,000		
	22	21	5	12	26	10	26	10	17	17	5	13	32	3	0	3	22	10	13	15	32	1	0	48	1	0	48	0	48	Within ±1,000	
	28	9	1	11	14	13	17	18	3	17	18	3	17	21	0	0	24	12	2	25	13	0	0	38	0	0	38	0	38	- 1 to 3,000	
Phosphorus .04 to .069	9	3	0	1	6	5	4	7	1	3	1	0	9	0	0	1	6	1	4	10	2	0	0	12	0	0	12	0	12	- 3 " 5,000	
	1	1	1	1	1	1	2	0	1	0	1	0	2	1	0	0	3	0	0	2	1	0	0	3	0	0	3	0	3	- over 5,000	
	10	13	6	6	9	14	12	13	4	1	3	0	2	2	0	0	2	1	1	0	0	0	2	2	4	2	4	2	4	+ over 5,000	
	17	28	3	9	26	13	12	27	9	2	33	13	0	18	10	0	15	4	9	0	9	0	0	17	3	29	3	29	+ 3 to 5,000		
	18	26	8	13	26	14	15	29	8	3	34	13	2	3	13	0	3	23	16	6	0	28	19	1	48	1	48	1	48	+ 1 " 3,000	
Phosphorus .07 to .099	14	15	8	7	14	16	9	14	14	1	21	14	1	14	1	4	16	9	8	3	29	5	0	37	5	0	37	0	37	- 1 to 3,000	
	6	9	0	1	8	6	3	5	7	0	9	6	0	9	0	0	9	4	2	5	10	0	15	0	0	15	0	15	- 3 " 5,000		
	0	2	1	1	2	0	0	1	2	0	1	2	0	1	2	0	1	0	1	0	3	0	0	3	0	0	3	0	3	- over 5,000	
	2	2	0	2	2	2	3	0	1	0	3	1	0	3	1	0	3	0	1	0	0	3	1	4	4	2	4	2	4	+ over 5,000	
	2	7	3	1	6	5	2	9	1	0	4	8	0	4	8	0	8	1	3	0	1	9	2	12	12	12	12	12	12	+ 3 to 5,000	
Phosphorus .11 to .139	3	14	6	0	10	13	4	12	7	0	3	16	4	3	16	4	5	13	3	2	0	0	12	11	23	1	23	1	23	+ 1 " 3,000	
	4	6	3	3	1	9	1	8	4	0	3	7	3	3	7	3	2	5	3	3	0	3	6	4	13	4	13	4	13	Within ±1,000	
	4	6	2	0	6	6	3	6	3	0	3	7	2	3	7	2	7	2	3	0	7	4	1	12	1	12	1	12	1	12	- 1 to 3,000
	0	2	2	0	2	2	2	2	0	0	1	2	1	2	1	2	1	1	1	0	3	0	1	4	0	1	4	0	1	- 3 " 5,000	
	0	1	0	0	0	1	1	1	0	0	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	- over 5,000	

TABLE XIII.—*Manganese, both Mille.*

	Carbon.				Sulphur.				Phosphorus.				Estimated Ultimates.				Thickness.				Actual Ultimates.				All Tests.
	96 to 100.	10 to 12.	13 to 18.		Under 40.	44 to 58.	66 to 79.		Under 40.	44 to 58.	66 to 79.		Under 40.	44 to 58.	66 to 79.	Over 10,000.	4 in. and 1/2 in.	1/2 in. and 1 in.	1 in. and 1 1/2 in.	46 to 54,000.	54 to 62,000.	62 to 70,000.	Over 70,000.		
Manganese under 40	3	1	2	0	1	5	5	1	0	5	0	5	0	2	1	0	2	2	2	0	0	5	1	6	+ over 5,000
"	12	4	1	3	7	7	7	8	2	8	1	10	1	0	5	0	3	8	3	2	9	6	17	+ 3 to 5,000	
"	19	12	0	11	15	5	11	17	3	7	23	2	0	4	12	6	9	9	4	24	3	0	31	+ 1 " 3,000	
"	22	13	4	13	15	11	28	11	0	18	19	2	0	1	20	9	9	19	19	1	0	39	Within ±1,000		
"	24	8	1	10	18	5	19	12	2	16	15	2	0	0	17	2	14	23	10	1	0	33	- 1 to 3,000		
"	4	6	1	0	5	6	4	4	3	2	6	3	0	1	3	4	3	4	7	0	0	11	- 3 " 5,000		
"	.1	1	2	1	2	1	3	0	1	0	2	2	0	0	2	0	2	2	2	0	0	4	- over 5,000		
Manganese 40 to 549	2	2	0	2	3	5	4	4	2	0	5	5	0	2	6	0	2	0	1	4	5	10	+ over 5,000		
"	5	14	4	3	6	14	4	13	6	0	13	9	1	6	14	2	1	0	4	13	6	23	+ 3 to 5,000		
"	11	23	7	5	21	15	6	23	12	1	19	20	1	0	30	7	4	0	16	21	4	41	+ 1 " 3,000		
"	15	27	7	9	25	15	15	26	8	3	32	12	2	2	24	16	7	3	34	10	2	49	Within ±1,000		
"	18	18	7	11	17	15	28	14	6	4	31	7	1	0	16	15	12	10	30	2	1	43	- 1 to 3,000		
"	9	9	3	1	15	5	8	10	3	1	13	6	1	0	7	8	6	8	11	1	1	21	- 3 " 5,000		
"	2	1	1	0	2	2	2	2	0	0	3	1	0	0	0	0	4	2	2	0	0	4	- over 5,000		
Manganese 55 to 75	0	2	0	0	2	0	0	0	2	0	0	2	0	1	1	0	0	0	0	0	2	2	+ over 5,000		
"	2	2	0	2	0	2	0	3	1	0	3	1	0	1	2	1	0	0	3	1	4	4	+ 3 to 5,000		
"	4	10	3	4	7	6	5	7	5	0	8	7	2	0	12	1	4	0	6	7	4	17	+ 1 " 3,000		
"	6	9	3	0	10	8	6	9	3	0	10	6	2	0	9	8	1	0	10	6	2	18	Within ±1,000		
"	8	7	3	4	6	8	3	11	4	0	9	7	2	0	10	3	5	0	14	3	1	18	- 1 to 3,000		
"	4	8	2	1	6	7	2	11	1	0	5	8	1	1	6	5	2	2	10	2	0	14	- 3 " 5,000		
"	0	3	0	0	1	2	0	3	0	0	0	0	3	0	.1	1	1	0	3	0	0	3	- over 5,000		

TABLE XIII.A.—Manganese, corrected for Size, both Mills.

	Carbon.			Sulphur.			Phosphorus.			Estimated Ultimate.				Thickness.				Actual Ultimate.				All Tests.
	.06 to .09.	.10 to .12.	.13 to .18.	Under .04.	.04 to .059.	.06 to .079.	Under .04.	.04 to .059.	.06 to .079.	46 to 54,000.	54 to 62,000.	62 to 70,000.	Over 70,000.	Under 3 in.	3 in. and 4 in.	4 in. to 5 in.	5 in. to 7 in.	40 to 54,000.	54 to 62,000.	62 to 70,000.	Over 70,000.	
Manganese under .40	2	3	1	0	2	1	3	0	0	0	0	0	0	0	2	3	1	0	0	5	0	6
"	13	7	1	8	7	12	2	7	12	6	12	2	0	0	8	8	5	5	12	4	0	21
"	21	8	2	16	8	15	12	12	17	17	17	2	0	3	10	9	8	8	18	4	1	31
"	22	16	4	13	20	9	26	15	1	14	25	3	0	5	20	3	14	16	24	2	0	42
"	22	6	1	8	13	8	17	9	8	14	12	3	0	3	17	5	4	18	10	1	0	29
"	5	3	1	1	3	5	4	3	2	2	6	1	0	1	5	1	2	5	4	0	0	9
"	0	2	1	1	1	1	2	0	1	0	1	2	0	1	2	0	0	1	2	0	0	3
Manganese .40 to .649.	1	3	3	1	2	4	4	3	0	0	5	2	0	0	4	0	3	0	1	4	2	7
"	5	11	8	3	8	13	2	13	9	0	9	15	0	1	15	4	5	0	2	17	5	24
"	14	31	8	5	31	17	14	27	12	2	32	17	2	4	29	15	5	1	27	19	6	53
"	16	31	7	14	24	16	17	29	8	2	37	13	2	3	25	14	12	3	39	8	4	54
"	17	14	7	7	13	18	18	14	6	4	22	11	1	1	17	13	7	10	24	3	1	38
"	9	4	1	10	3	7	5	2	1	1	11	1	1	1	7	2	4	9	4	0	1	14
"	0	0	1	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	1	0	0	1
Manganese .65 to .75.	0	1	0	0	1	0	0	1	0	0	1	0	1	0	1	0	2	0	0	1	1	6
"	3	3	0	3	2	1	1	4	1	0	5	1	0	0	3	1	0	0	1	5	0	1
"	6	12	3	9	9	5	9	7	0	8	11	2	2	2	11	5	3	0	7	8	6	21
"	6	6	5	1	8	6	5	8	4	0	7	7	3	0	7	5	5	0	11	3	3	17
"	7	10	3	3	8	9	3	14	3	0	11	7	2	0	13	5	2	0	15	5	0	20
"	1	7	0	0	3	5	1	7	0	0	2	6	0	0	4	3	1	1	7	0	0	8
"	1	2	0	1	1	1	2	2	0	0	2	1	0	1	2	0	0	1	2	0	0	3

TABLE XIV.—*Estimated Ultimate Strengths, both Mills.*

Lbs. per Square Inch.	Carbon.			Sulphur.			Phosphorus.			Manganese.			Thickness.				All Tests.	
	.08 to ".09.	.10 to ".12.	.13 to ".18.	Under ".04.	.04 to ".08.	.08 to ".079.	Under ".04.	.04 to ".069.	.07 to ".099.	Under ".04.	.04 to ".049.	.05 to ".075.	Under ".04.	.04 to ".05 in.	.05 to ".06 in.	.06 to ".08 in.		
46 to 54,000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	over 5,000
"	6	0	0	2	4	0	5	1	0	6	0	0	0	1	1	0	6	+ 3 to 5,000
"	8	0	0	6	2	0	6	2	0	7	1	0	0	0	4	3	8	+ 1 " 3,000
"	21	0	0	10	7	4	20	1	0	18	3	0	1	9	5	6	21	Within ±1,000
"	20	0	0	10	8	2	17	3	0	16	4	0	0	11	4	5	20	- 1 to 3,000
"	3	0	0	1	1	1	3	0	0	2	1	0	0	1	2	0	3	- 3 " 5,000
"	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	- over 5,000
54 to 62,000	5	2	3	2	3	5	4	2	4	5	5	0	2	5	0	3	10	+ over 5,000
"	13	13	0	6	8	12	6	16	4	10	13	3	6	14	4	2	26	+ 3 " 5,000
"	26	23	0	13	25	11	16	30	3	22	19	8	-4	28	7	10	49	+ 1 " 3,000
"	21	36	4	9	35	17	28	32	1	19	32	10	0	32	20	9	61	Within ±1,000
"	28	12	2	13	25	17	26	25	4	15	31	9	0	25	13	17	55	- 1 to 3,000
"	3	2	0	0	15	8	11	12	1	6	13	5	0	12	7	5	24	- 3 " 5,000
"	0	3	5	0	3	2	4	1	0	2	3	0	0	1	0	4	5	- over 5,000
62 to 70,000	0	3	5	0	3	5	1	2	5	1	5	2	3	4	0	1	8	+ over 5,000
"	0	7	4	0	1	10	0	6	5	1	9	1	4	6	1	0	11	+ 3 to 5,000
"	0	22	7	1	14	14	0	15	14	2	20	7	0	20	3	6	29	+ 1 " 3,000
"	1	13	6	3	6	11	1	12	7	2	12	6	1	10	7	2	20	Within ±1,000
"	2	8	6	2	7	7	2	9	5	2	7	7	0	7	2	7	16	- 1 to 3,000
"	2	11	4	0	9	8	0	12	5	3	6	6	2	3	8	4	17	- 3 " 5,000
"	0	3	3	1	2	3	1	4	1	2	1	3	0	2	1	3	6	- over 5,000
Over 70,000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	+ over 5,000
"	0	0	0	0	0	0	0	1	0	0	1	0	0	1	0	0	1	+ 3 to 5,000
"	0	0	3	0	2	1	0	0	3	0	1	2	0	2	1	0	3	+ 1 " 3,000
"	0	0	4	0	2	2	0	1	3	0	2	2	1	2	1	0	4	Within ±1,000
"	0	0	3	0	1	2	0	0	3	0	1	2	0	0	1	2	3	- 1 to 3,000
"	0	0	2	0	1	1	0	1	1	0	1	1	0	0	0	2	2	- 3 " 5,000
"	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	- over 5,000

TABLE XV.—*Thickness, both Mills.*

	Carbon.			Sulphur.		Phosphorus.		Manganese.			Estimated Ultimates.					Actual Ultimates.					All Tests.		
	06 to 09.	10 to 12.	13 to 18.	Under 04.	04 to 05.	06 to 07.	07 to 08.	Under 40.	40 to 49.	50 to 55.	75.	46 to 54.	54 to 62.	62 to 70.	Over 70,000.	46 to 54.	54 to 62.	62 to 70.	Over 70,000.				
Plates under $\frac{1}{8}$ in.	2	1	2	1	1	3	1	1	3	2	1	0	0	2	3	0	0	2	3	5	5	12	4
"	4	6	2	0	4	8	2	6	4	5	6	1	1	6	4	1	0	3	4	5	1	12	4
"	3	1	0	2	1	1	1	3	0	4	0	0	0	4	0	0	0	4	0	0	1	4	4
"	1	0	2	0	0	3	1	1	1	1	2	0	1	0	1	1	1	0	1	1	3	3	4
"	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
"	0	0	0	0	1	1	0	1	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0
"	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Plates $\frac{1}{8}$ in. and $\frac{1}{4}$ in.	2	3	4	1	3	5	2	2	5	2	6	1	0	5	4	0	0	1	4	4	9	9	9
"	12	10	2	7	5	12	5	14	5	8	14	2	4	14	6	0	1	13	2	24	13	2	24
"	19	29	6	10	27	17	13	27	14	12	30	12	4	28	20	2	1	25	23	6	54	6	54
"	21	26	6	12	20	21	24	24	5	20	24	9	9	32	10	2	10	33	8	2	53	2	53
"	26	16	1	11	14	18	22	14	7	17	16	10	11	25	7	0	17	23	3	0	43	0	43
"	8	7	1	2	7	7	6	9	1	3	7	6	1	12	3	0	8	7	1	0	16	0	16
"	0	2	1	1	1	1	2	1	0	2	0	1	0	1	2	0	1	2	0	0	3	0	3
Plates $\frac{1}{4}$ in. and $\frac{1}{2}$ in.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
"	3	2	1	1	3	2	2	4	0	3	2	1	1	4	1	0	1	1	4	0	6	1	6
"	6	6	2	4	7	3	4	8	2	6	7	1	3	7	3	1	2	8	3	1	14	1	14
"	12	17	4	5	19	9	15	14	4	9	16	8	5	20	7	1	5	20	7	1	83	1	83
"	10	7	3	6	10	4	11	7	2	2	15	3	4	13	2	1	6	12	2	0	20	0	20
"	7	9	1	0	10	7	6	9	2	4	8	5	2	7	8	0	5	12	0	0	17	0	17
"	0	1	0	0	0	1	0	1	0	0	1	0	0	0	1	0	0	1	0	0	1	0	1
Plates $\frac{1}{2}$ in. to 1 in.	1	1	2	0	2	2	2	1	1	2	2	0	0	3	1	0	0	0	3	1	4	4	4
"	0	2	0	1	1	2	0	0	1	1	1	0	0	2	0	0	0	1	1	0	2	1	2
"	6	9	2	4	8	5	4	9	4	9	4	4	1	10	6	0	1	9	6	1	17	1	17
"	9	6	2	5	11	1	9	7	1	9	7	1	6	9	2	0	6	10	1	0	17	0	17
"	14	10	7	8	17	6	12	16	3	14	12	5	5	17	7	2	9	10	1	2	31	1	31
"	2	5	4	0	8	3	2	6	3	3	6	2	0	5	4	2	1	7	2	1	11	1	11
"	3	2	2	0	4	3	3	3	1	2	4	1	0	4	3	0	3	4	0	0	7	0	7

TABLE XVI.A.—Actual Ultimate Strengths, corrected for Size, both Mills.

Lbs. per Square Inch.	Carbon.			Sulphur.			Phosphorus.			Manganese.			Thickness.			All Tests.
	.06 to .09.	.10 to .12.	.13 to .18.	Under .04.	.04 to .069.	.06 to .079.	Under .04.	.04 to .069.	.07 to .099.	Under .40.	.40 to .540.	.55 to .75.	Under $\frac{3}{8}$ in.	$\frac{3}{8}$ in. and $\frac{1}{2}$ in.	$\frac{3}{8}$ to 1 in.	
46 to 54,000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
"	5	0	0	4	1	0	5	0	0	5	0	0	0	1	3	5
"	9	0	0	6	1	1	9	0	0	8	1	0	0	4	4	9
"	19	0	0	7	2	2	15	4	0	16	3	0	0	8	9	19
"	28	0	0	11	6	6	25	3	0	18	10	0	0	18	8	28
"	14	1	0	9	5	5	10	5	0	5	9	1	1	8	2	15
"	1	1	0	1	2	1	2	0	0	1	0	1	0	2	0	2
54 to 62,000	0	2	0	1	1	0	2	0	0	1	1	0	0	1	0	2
"	10	5	0	6	7	2	5	9	1	12	2	1	0	6	2	15
"	28	21	3	13	29	10	24	28	0	18	27	7	0	23	18	52
"	24	44	6	15	41	18	32	39	3	24	39	11	4	34	17	74
"	18	26	5	7	21	21	13	29	7	10	24	15	3	25	13	49
"	1	13	1	1	7	7	2	10	3	4	4	7	2	8	4	15
"	0	3	2	2	2	1	1	3	1	2	2	2	0	0	3	5
62 to 70,000	3	3	3	0	3	6	4	2	3	5	4	0	0	4	4	9
"	6	16	4	4	9	13	0	17	9	4	17	5	1	14	5	26
"	4	25	2	0	15	16	0	19	12	4	19	8	4	21	6	31
"	1	8	4	3	3	7	1	6	6	2	8	3	1	8	1	13
"	0	4	5	0	2	7	0	5	4	1	3	5	1	4	2	9
"	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
"	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Over 70,000	0	2	1	0	1	2	0	2	1	0	2	1	0	2	1	3
"	0	0	5	0	1	4	0	3	2	0	5	0	0	5	0	5
"	0	5	8	0	6	7	1	1	11	1	6	6	5	5	2	13
"	0	1	6	0	1	6	0	3	4	0	4	3	3	2	0	7
"	0	0	1	0	0	1	0	0	1	0	1	0	0	0	1	1
"	0	0	1	0	0	1	0	0	1	0	1	0	1	0	0	1
"	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

TABLE XVII.—*Summary of Averages of Universal Mill Tests.*

	Number of Tests.	Ultimate Strengths.		
		Actual.	Calculated.	Difference.
Carbon '06 to '09	67	55,721	56,119	- 398
" '10 " '12	82	61,250	61,516	- 266
" '13 " '18	22	65,298	65,749	- 451
Sulphur under '04	27	57,480	57,292	+ 188
" '04 to '059	90	58,819	59,554	- 735
" '06 " '079	54	61,976	61,927	+ 49
Phosphorus under '04	57	55,468	56,092	- 624
" '04 to '069	82	60,019	60,589	- 570
" '07 " '099	32	65,911	65,164	+ 747
Manganese under '40	57	56,938	56,955	- 17
" '40 to '549	78	59,973	60,531	- 558
" '55 " '75	36	63,028	63,415	- 387
Actual ultimates . . 46 to 54,000	30	51,647	53,561	- 1,914
" " . . 54 " 62,000	89	58,415	59,607	- 1,192
" " . . 62 " 70,000	42	64,509	62,663	+ 1,846
" " . . over 70,000	10	73,461	70,703	+ 2,758
Estimated ultimates . . 46 to 54,000	21	52,241	52,389	- 148
" " . . 54 " 62,000	95	58,356	58,602	- 246
" " . . 62 " 70,000	51	63,717	64,452	- 735
" " . . over 70,000	4	75,450	74,062	+ 1,388
Estimated ultimates, } corrected for size . . 46 to 54,000	29	52,277	51,778	+ 499
" " . . 54 " 62,000	101	59,165	58,520	+ 645
" " . . 62 " 70,000	36	64,615	64,407	+ 208
" " . . over 70,000	5	74,916	73,910	+ 1,006
Thickness under $\frac{3}{8}$ in.	7	65,530	61,921	+ 3,609
" $\frac{3}{8}$ in. and $\frac{7}{8}$ in.	48	61,961	61,558	+ 403
" $\frac{7}{8}$ in. " $\frac{3}{4}$ in.	54	58,733	59,516	- 783
" $\frac{3}{4}$ in. to 1 in.	62	57,869	58,848	- 979
Thickness, corrected } for size under $\frac{3}{8}$ in.	7	65,530	64,921	+ 609
" " $\frac{3}{8}$ in. and $\frac{7}{8}$ in.	48	61,961	61,350	+ 611
" " $\frac{7}{8}$ in. " $\frac{3}{4}$ in.	54	58,733	58,484	+ 249
" " $\frac{3}{4}$ in. to 1 in.	62	57,869	57,086	+ 783
All tests	171	59,604	59,946	- 342
All tests, corrected for size	171	59,604	59,045	+ 559

TABLE XVIII.—*Summary of Averages of Sheared Mill Tests.*

	Number of Tests.	Ultimate Strengths.		
		Actual.	Calculated.	Difference.
Carbon '06 to '09	104	55,436	55,816	+ 120
" '10 " '12	98	61,159	60,806	+ 353
" '13 " '18	35	67,927	66,982	+ 945
Sulphur under '04	53	55,869	55,748	+ 121
" '04 to '069	94	59,302	59,024	+ 278
" '06 " '079	90	62,234	61,704	+ 530
Phosphorus under '04	94	55,510	55,758	- 248
" '04 to '069	106	60,913	60,397	+ 516
" '07 " '099	37	66,532	65,212	+ 1,320
Manganese under '40	84	56,074	55,728	+ 346
" '40 to '49	113	61,524	60,836	+ 688
" '55 " '75	40	61,853	62,517	- 664
Actual ultimates . . 46 to 54,000	48	51,605	53,110	- 1,505
" " . . 54 " 62,000	123	58,541	58,628	- 87
" " . . 62 " 70,000	46	65,685	65,639	+ 46
" " . . over 70,000	20	71,863	68,809	+ 3,054
Estimated ultimates . 46 to 54,000	37	51,858	52,148	- 290
" " . . 54 " 62,000	135	58,429	58,098	+ 331
" " . . 62 " 70,000	56	65,911	64,900	+ 1,011
" " . . over 70,000	9	70,974	72,130	- 1,156
Estimated ultimates, } corrected for size . 46 to 54,000	38	52,016	52,049	- 33
" " . . 54 " 62,000	133	58,381	58,048	+ 333
" " . . 62 " 70,000	55	65,586	64,898	+ 688
" " . . over 70,000	11	71,622	72,076	- 454
Thickness under $\frac{3}{8}$ in.	19	64,075	61,260	+ 2,815
" $\frac{3}{8}$ in. and $\frac{7}{8}$ in.	154	59,127	58,679	+ 448
" $\frac{7}{8}$ in. " $1\frac{1}{8}$ in.	37	58,372	58,899	- 527
" $\frac{3}{8}$ in. to 1 in.	27	61,247	62,090	- 843
Thickness, corrected } for size under $\frac{3}{8}$ in.	19	64,075	64,576	- 501
" " $\frac{3}{8}$ in. and $\frac{7}{8}$ in.	154	59,127	58,821	+ 306
" " $\frac{7}{8}$ in. " $1\frac{1}{8}$ in.	37	58,372	57,899	+ 473
" " $\frac{3}{8}$ in. to 1 in.	27	61,247	60,479	+ 768
All tests	237	59,648	59,309	+ 339
All tests, corrected for size	237	59,648	59,327	+ 321

TABLE XIX.—*Estimated Ultimate Strength in Tons of 2240 Pounds.*

Carbon	'06	'07	'08	'09	'10	'11	'12	'13	'14	'15	'16	'17	'18	'19	'20	'21	'22	'23	'24	'25
Phos. '000	17.66	18.01	18.37	18.73	19.08	19.44	19.8	20.16	20.51	20.87	21.23	21.57	21.94	22.30	22.65	23.01	23.37	23.73	24.08	24.44
" '005	17.83	18.19	18.55	18.93	19.31	19.69	20.07	20.45	20.83	21.20	21.56	21.92	22.28	22.63	22.99	23.35	23.70	24.06	24.42	24.78
" '01	18.01	18.37	18.73	19.13	19.53	19.93	20.33	20.74	21.14	21.54	21.90	22.25	22.61	22.97	23.33	23.67	24.04	24.40	24.75	25.11
" '015	18.19	18.55	18.90	19.33	19.75	20.18	20.60	21.03	21.45	21.87	22.23	22.58	22.94	23.30	23.66	24.02	24.37	24.72	25.09	25.45
" '02	18.37	18.73	19.08	19.53	19.96	20.42	20.87	21.32	21.76	22.21	22.57	22.92	23.28	23.63	24.00	24.36	24.69	25.07	25.42	25.78
" '025	18.55	18.90	19.26	19.73	20.20	20.66	21.14	21.61	22.08	22.55	22.90	23.26	23.61	23.97	24.34	24.68	25.04	25.40	25.75	26.12
" '03	18.73	19.08	19.44	19.93	20.42	20.91	21.41	21.90	22.39	22.88	23.24	23.60	23.95	24.30	24.66	25.03	25.37	25.72	26.09	26.45
" '035	18.90	19.26	19.62	20.13	20.65	21.16	21.68	22.19	22.70	23.21	23.57	23.93	24.29	24.63	25.00	25.36	25.69	26.07	26.42	26.78
" '04	19.08	19.44	19.80	20.33	20.87	21.40	21.95	22.48	23.01	23.55	23.90	24.26	24.62	24.98	25.34	25.68	26.05	26.40	26.75	27.12
" '045	19.26	19.62	19.98	20.53	21.09	21.65	22.21	22.77	23.33	23.88	24.24	24.60	24.95	25.31	25.66	26.03	26.38	26.72	27.09	27.46
" '05	19.44	19.80	20.16	20.73	21.32	21.90	22.48	23.06	23.64	24.22	24.57	24.93	25.29	25.64	26.00	26.36	26.70	27.08	27.43	27.78
" '055	19.62	19.98	20.33	20.93	21.54	22.14	22.74	23.35	23.95	24.55	24.91	25.27	25.62	25.98	26.34	26.68	27.05	27.41	27.76	28.12
" '06	19.80	20.16	20.51	21.13	21.76	22.39	23.01	23.64	24.26	24.89	25.25	25.61	25.95	26.31	26.66	27.03	27.38	27.73	28.10	28.46
" '065	19.98	20.33	20.69	21.34	21.99	22.63	23.28	23.93	24.58	25.22	25.58	25.94	26.30	26.64	27.00	27.37	27.70	28.08	28.43	28.78
" '07	20.16	20.51	20.87	21.54	22.21	22.88	23.55	24.22	24.89	25.56	25.91	26.28	26.63	26.98	27.35	27.69	28.05	28.41	28.76	29.13
" '075	20.33	20.69	21.05	21.74	22.43	23.12	23.82	24.51	25.20	25.89	26.25	26.61	26.96	27.32	27.67	28.04	28.38	28.73	29.10	29.47
" '08	20.51	20.87	21.23	21.94	22.66	23.37	24.09	24.80	25.51	26.23	26.59	26.94	27.30	27.65	28.01	28.37	28.70	29.08	29.43	29.79
" '085	20.69	21.05	21.40	22.14	22.87	23.61	24.35	25.09	25.83	26.56	26.92	27.28	27.63	27.99	28.35	28.69	29.06	29.41	29.76	30.13
" '09	20.87	21.23	21.58	22.34	23.10	23.86	24.62	25.38	26.14	26.90	27.26	27.61	27.96	28.32	28.67	29.04	29.39	29.73	30.11	30.47
" '095	21.05	21.40	21.76	22.54	23.32	24.11	24.89	25.67	26.45	27.23	27.60	27.94	28.30	28.65	29.01	29.37	29.71	30.09	30.44	30.79
" '10	21.23	21.58	21.94	22.74	23.55	24.35	25.16	25.96	26.76	27.57	27.92	28.28	28.64	28.99	29.35	29.69	30.05	30.42	30.77	31.14
'01 Phos. =	.857	.867	.867	.402	.446	.491	.536	.580	.625	.670	.670	.670	.670	.670	.670	.670	.670	.670	.670	.670

TABLE XIX. (continued)—Additions for Manganese.

Mn.	Tons.	Mn.	Tons.	Mn.	Tons.	Mn.	Tons.	Mn.	Tons.	Mn.	Tons.
...	...	21	2.241	31	3.161	41	3.902	51	4.464	61	4.911
...	...	215	2.290	315	3.201	415	3.933	515	4.487	615	4.933
...	...	22	2.339	32	3.241	42	3.964	52	4.509	62	4.955
...	...	225	2.388	325	3.281	425	3.996	525	4.531	625	4.978
...	...	23	2.437	33	3.321	43	4.027	53	4.554	63	5.000
...	...	235	2.487	335	3.362	435	4.058	535	4.576	635	5.021
...	...	24	2.536	34	3.402	44	4.089	54	4.598	64	5.045
...	...	245	2.585	345	3.442	445	4.121	545	4.621	645	5.067
15	1.607	25	2.634	35	3.482	45	4.152	55	4.643	65	5.090
155	1.661	255	2.679	355	3.518	455	4.179	555	4.665	655	5.112
16	1.714	26	2.723	36	3.554	46	4.205	56	4.687	66	5.134
165	1.741	265	2.768	365	3.589	465	4.232	565	4.710	665	5.156
17	1.821	27	2.812	37	3.625	47	4.259	57	4.732	67	5.179
175	1.875	275	2.857	375	3.661	475	4.286	575	4.755	675	5.201
18	1.928	28	2.902	38	3.696	48	4.312	58	4.777	68	5.223
185	1.982	285	2.946	385	3.732	485	4.339	585	4.799	685	5.246
19	2.036	29	2.991	39	3.768	49	4.366	59	4.822	69	5.268
195	2.089	295	3.036	395	3.804	495	4.393	595	4.844	695	5.290
20	2.143	30	3.080	40	3.839	50	4.42	60	4.866	70	5.313
205	2.196	305	3.120	405	3.870	505	4.442	605	4.888	705	5.335

Additions for Sulphur.

	.000	.001	.002	.003	.004	.005	.006	.007	.008	.009
0	.000	.022	.045	.067	.089	.112	.134	.156	.178	.201
01	.2232	.245	.2679	.290	.313	.335	.357	.379	.402	.424
02	.446	.469	.491	.513	.536	.558	.580	.603	.625	.647
03	.670	.692	.714	.737	.759	.781	.804	.826	.848	.871
04	.893	.915	.937	.960	.982	1.004	1.027	1.049	1.072	1.094
05	1.116	1.138	1.160	1.183	1.205	1.228	1.250	1.272	1.295	1.317
06	1.339	1.361	1.383	1.406	1.428	1.451	1.473	1.495	1.518	1.540
07	1.562	1.584	1.606	1.630	1.652	1.674	1.696	1.719	1.741	1.763

TABLE XX.—Estimated Ultimate Strengths (Kilogrammes per Square Millimetre).

Carbon =	'06	'07	'08	'09	'10	'11	'12	'13	'14	'15	'16	'17	'18	'19	'20	'21	'22	'23	'24	'25
Phos. '000	27.8	28.4	28.9	29.4	30.0	30.6	31.2	31.7	32.2	32.9	33.4	34.0	34.5	35.1	35.7	36.2	36.8	37.4	37.9	38.5
" '005	28.1	28.6	29.1	29.9	30.4	31.0	31.6	32.2	32.8	33.4	33.9	34.5	35.1	35.6	36.2	36.8	37.3	37.9	38.4	39.0
" '01	28.4	28.9	29.5	30.1	30.7	31.4	32.0	32.6	33.3	33.9	34.5	35.0	35.6	36.2	36.7	37.3	37.8	38.4	39.0	39.5
" '015	28.6	29.2	29.8	30.4	31.1	31.8	32.4	33.1	33.8	34.4	35.0	35.6	36.1	36.7	37.2	37.8	38.4	38.9	39.5	40.1
" '02	28.9	29.5	30.0	30.7	31.4	32.2	32.9	33.6	34.3	35.0	35.5	36.1	36.6	37.2	37.8	38.3	38.9	39.5	40.0	40.6
" '025	29.2	29.8	30.3	31.1	31.8	32.5	33.3	34.0	34.8	35.5	36.1	36.6	37.2	37.7	38.3	38.9	39.4	40.0	40.5	41.1
" '03	29.5	30.0	30.6	31.4	32.2	32.9	33.7	34.5	35.2	36.0	36.6	37.1	37.7	38.3	38.8	39.4	40.0	40.5	41.1	41.6
" '035	29.8	30.3	30.9	31.7	32.5	33.3	34.1	34.9	35.7	36.5	37.1	37.7	38.2	38.8	39.4	39.9	40.5	41.0	41.6	42.2
" '04	30.0	30.6	31.2	32.0	32.8	33.7	34.5	35.4	36.2	37.1	37.6	38.2	38.8	39.3	39.9	40.4	41.0	41.6	42.1	42.7
" '045	30.3	30.9	31.4	32.3	33.2	34.1	35.0	35.8	36.7	37.6	38.2	38.7	39.3	39.9	40.4	41.0	41.5	42.1	42.7	43.2
" '05	30.6	31.2	31.7	32.6	33.6	34.5	35.4	36.3	37.2	38.1	38.7	39.3	39.8	40.4	40.9	41.5	42.1	42.6	43.2	43.8
" '055	30.9	31.4	32.0	33.0	33.9	34.9	35.8	36.8	37.7	38.7	39.2	39.8	40.3	40.9	41.5	42.0	42.6	43.2	43.7	44.3
" '06	31.2	31.7	32.3	33.3	34.3	35.2	36.2	37.2	38.2	39.2	39.7	40.3	40.9	41.4	42.0	42.5	43.1	43.7	44.2	44.8
" '065	31.4	32.0	32.6	33.6	34.6	35.6	36.6	37.7	38.7	39.7	40.3	40.8	41.4	42.0	42.5	43.1	43.6	44.2	44.8	45.3
" '07	31.7	32.3	32.9	33.9	35.0	36.0	37.1	38.1	39.1	40.2	40.8	41.4	42.0	42.5	43.0	43.6	44.2	44.7	45.3	45.9
" '075	32.0	32.6	33.1	34.2	35.3	36.4	37.5	38.6	39.7	40.8	41.3	41.9	42.4	43.0	43.6	44.1	44.7	45.3	45.8	46.4
" '08	32.3	32.9	33.4	34.5	35.7	36.8	37.9	39.0	40.2	41.3	41.9	42.4	43.0	43.5	44.1	44.7	45.2	45.8	46.4	46.9
" '085	32.6	33.1	33.7	34.9	36.0	37.2	38.3	39.5	40.7	41.8	42.4	42.9	43.5	44.1	44.6	45.2	45.8	46.3	46.9	47.4
" '09	32.9	33.4	34.0	35.2	36.4	37.6	38.8	40.0	41.2	42.3	42.9	43.5	44.0	44.7	45.2	45.7	46.3	46.8	47.4	48.0
" '095	33.1	33.7	34.3	35.5	36.7	38.0	39.2	40.4	41.6	42.9	43.4	44.0	44.6	45.1	45.7	46.3	46.8	47.4	47.9	48.5
" '10	33.4	34.0	34.5	35.8	37.1	38.3	39.6	40.9	42.1	43.4	44.0	44.5	45.1	45.6	46.2	46.8	47.3	47.9	48.5	49.0
*001 Phos. =	0.05	0.06	0.06	0.06	0.07	0.08	0.09	0.10	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11

TABLE XX. (continued)—Additions for Manganese.

Man.	Kilo.	Man.	Kilo.	Man.	Kilo.	Man.	Kilo.	Man.	Kilo.	Man.	Kilo.
...	...	21	3.48	31	4.97	41	6.15	51	7.02	61	7.73
...	...	215	3.57	315	5.04	415	6.20	515	7.06	615	7.77
...	...	22	3.65	32	5.10	42	6.25	52	7.09	62	7.80
...	...	225	3.73	325	5.17	425	6.30	525	7.13	625	7.84
...	...	23	3.81	33	5.23	43	6.35	53	7.16	63	7.87
...	...	235	3.89	335	5.30	435	6.40	535	7.20	635	7.91
...	...	24	3.89	34	5.36	44	6.45	54	7.23	64	7.94
...	...	245	4.05	345	5.43	445	6.50	545	7.27	645	7.95
15	2.53	25	4.13	35	5.49	45	6.55	55	7.30	65	8.01
155	2.61	255	4.21	355	5.55	455	6.59	555	7.34	655	8.05
16	2.68	26	4.28	36	5.60	46	6.63	56	7.37	66	8.08
165	2.77	265	4.35	365	5.66	465	6.67	565	7.41	665	8.12
17	2.85	27	4.42	37	5.71	47	6.71	57	7.45	67	8.15
175	2.93	275	4.41	375	5.77	475	6.75	575	7.49	675	8.19
18	3.01	28	4.56	38	5.83	48	6.79	58	7.52	68	8.22
185	3.09	285	4.63	385	5.88	485	6.83	585	7.56	685	8.26
19	3.17	28	4.70	39	5.94	49	6.87	59	7.59	69	8.27
195	3.25	285	4.77	395	5.99	495	6.91	595	7.63	695	8.31
20	3.33	30	4.84	40	6.05	50	6.95	60	7.66	70	8.34
205	3.41	305	4.91	405	6.10	505	6.99	605	7.70	705	8.40

Additions for Sulphur.

	0	001	002	003	004	005	006	007	008	009
0	00	04	07	11	14	17	21	25	28	32
01	35	39	42	46	49	52	56	60	63	67
02	70	74	77	81	84	87	91	95	98	1.02
03	1.05	1.09	1.12	1.16	1.19	1.22	1.26	1.30	1.33	1.37
04	1.40	1.44	1.47	1.51	1.54	1.57	1.61	1.65	1.68	1.72
05	1.75	1.79	1.82	1.86	1.87	1.92	1.96	2.00	2.03	2.07
06	2.10	2.14	2.17	2.21	2.24	2.27	2.31	2.35	2.38	2.42
07	2.45	2.49	2.52	2.56	2.59	2.62	2.66	2.70	2.73	2.77

TABLE XXI.—*Summary of Averages of 408 Tests of both Mills.*

	Number of Tests.	Ultimate Strengths.			Per Cent. within 3,000.	Per Cent. within 4,000.	Per Cent. within 5,000.	After making Corrections for Size of Plates.
		Actual.	Calculated.	Difference.				
Carbon—								
‘06 to ‘09	171	55,548	55,630	- 82	74·3	88·3	95·3	{ 89·5 per cent. came within 5,000, being a gain of 8·8 p. ct.
‘10 „ ‘12	180	61,200	61,130	+ 70	70·6	82·8	94·4	
‘13 „ ‘18	57	66,912	66,506	+ 406	61·4	75·4	80·7	
Sulphur—								
Under ‘04	80	56,413	56,268	+ 145	83·8	93·8	96·3	{ 93·1 per cent. came within 5,000, being a gain of 3·5 p. ct.
‘04 to ‘059	184	59,065	59,283	- 218	72·8	86·4	94·0	
‘06 „ ‘079	144	62,138	61,788	+ 350	61·1	75·7	89·6	
Phosphorus—								
Under ‘04	151	55,494	55,884	- 390	76·9	89·5	93·4	{ 92·8 per cent. came within 5,000, being a gain of 7·3 p. ct.
‘04 to ‘069	188	60,523	60,480	+ 43	68·8	84·6	95·2	
‘07 „ ‘099	69	66,244	65,190	+ 1,054	62·6	70·1	85·5	
Manganese—								
Under ‘40	141	56,423	56,224	+ 199	73·0	84·4	92·9	{ 90·0 per cent. came within 5,000, being a gain of 16·7 per cent.
‘40 to ‘549	191	60,891	60,711	+ 180	70·2	85·3	92·7	
‘55 „ ‘79	76	62,409	62,942	- 533	68·4	80·3	93·4	
Actual ultimates—								
46 to 54,000	78	51,609	53,283	- 1,674	74·4	88·5	94·9	{ 90·0 per cent. came within 5,000, being a gain of 16·7 per cent.
54 „ 62,000	212	58,493	59,039	- 546	76·9	91·0	96·2	
62 „ 70,000	88	65,124	63,083	+ 2,041	61·2	73·9	89·8	
Over 70,000	30	72,398	69,441	+ 2,957	46·7	56·7	73·3	
Estimated ultimates—								
46 to 54,000	58	51,997	52,235	- 238	84·5	100·0	100·0	{ 90·0 per cent. came within 5,000, being a gain of 16·7 per cent.
54 „ 62,000	230	58,399	58,306	+ 93	71·7	83·0	93·5	
62 „ 70,000	107	64,866	64,686	+ 180	60·7	76·6	86·9	
Over 70,000	13	72,352	72,725	- 373	76·9	92·3	100·0	
Estimated ultimates, corrected for size—								
46 to 54,000	67	52,129	51,931	+ 198	79·1	94·0	100·0	{ 90·0 per cent. came within 5,000, being a gain of 16·7 per cent.
54 „ 62,000	234	58,719	58,252	+ 467	74·9	90·1	94·4	
62 „ 70,000	91	65,202	64,703	+ 499	68·1	83·5	91·2	
Over 70,000	16	72,653	72,424	+ 229	93·8	100·0	100·0	
Thickness—								
Under $\frac{3}{8}$ in.	26	64,466	61,438	+ 3,028	26·9	50·0	80·8	{ 90·0 per cent. came within 5,000, being a gain of 16·7 per cent.
$\frac{3}{8}$ in. and $\frac{7}{8}$ in.	202	59,800	59,363	+ 437	74·3	87·1	94·1	
$\frac{7}{8}$ in. „ $1\frac{1}{8}$ in.	91	58,586	59,265	- 679	73·6	92·3	98·9	
$\frac{3}{8}$ in. to 1 in.	89	58,894	59,832	- 938	73·0	78·7	87·7	
Thickness, corrected for size—								
Under $\frac{3}{8}$ in.	26	64,466	64,669	- 203	80·8	92·3	92·3	{ 90·0 per cent. came within 5,000, being a gain of 16·7 per cent.
$\frac{3}{8}$ in. and $\frac{7}{8}$ in.	202	59,800	59,422	+ 378	73·8	89·1	94·6	
$\frac{7}{8}$ in. „ $1\frac{1}{8}$ in.	91	58,586	58,246	+ 340	81·3	92·3	98·9	
$\frac{3}{8}$ in. to 1 in.	89	58,894	58,116	+ 778	68·5	88·8	92·1	
All tests	408	59,629	59,576	+ 53	70·8	84·1	92·9	{ 90·0 per cent. came within 5,000, being a gain of 16·7 per cent.
All tests, corrected for size	408	59,629	59,209	+ 420	74·7	89·7	94·9	

CORRESPONDENCE.

Mr. P. C. GILCHRIST, Member of Council, considered that the paper was one of the most important ever received by the Institute. It drew attention in a scientific manner to a great fact that had been well known by all those observers who had been connected with the production and manipulation of steel, the great fact in question being that within certain limits the chemical composition of a piece of steel was of less importance than its physical state. In plain English that meant that in the case of a plate you could make it hard and in an extreme case as brittle as a carrot by improper heating or rolling, and that you can make another piece from the very same plate almost as tough as leather.

Mr. R. A. HADFIELD, Member of Council, having been asked by the author to contribute some remarks to the discussion of his paper, did so from the point of view of one having practical experience with alloys of iron rather than from an acquaintance with that class of steel work, namely the production of plates, upon which the author's conclusions were based. He would first say that it seemed to him that the research in which the author was engaged deserved special attention, as any means that would help in more correctly meeting practical requirements should prove valuable. At present, in the preparation of structural metal, each steelmaker seemed to have his own particular and often perhaps haphazard method of arriving at the desired results as regarded mechanical tests. If analyses were compared, it was certainly remarkable to find how they varied so much and that there was no fixed standard. That might not be an objection, for, provided the consumer obtained the material he required, then it would seem that no one should grumble. Nevertheless there were often discrepancies in results which in many ways it would be better to avoid, and in any case the available knowledge in that direction was capable of much expansion. Therefore, any attempt such as the author was making, to co-ordinate facts on

the relative bearing of the chemical constituents and ultimate strength of steel, should be heartily encouraged. It was often found that unknown to each other different investigators were working in the same directions but in reality having the same bearing. Professor Arnold's paper, which appeared at the same meeting, gave some interesting results in a similar direction to that in which the author was seeking light. The results obtained by Professor Arnold at the Sheffield Technical School conclusively confirmed the previous knowledge that whatever value other elements might have on the hardening of the metal iron, speaking of comparatively small percentages of added elements, carbon was so far the only one to which it was necessary particularly to direct attention in the desire to materially alter the nature of the remelted product. In other words, changes in percentages of elements other than carbon could not give a steel which should vary in tenacity so much as to enable us to produce at will a high or low temper corresponding to those obtained with carbon steel. But, as the author rightly pointed out, there might still be many variations of types even in mild steels themselves, and for those interested in the production of such material it was in the direction he indicated that more light was required. As that work was naturally based upon ascertaining the actual value as regards tenacity of the metal iron itself, he gave further on the results of two sets of tests of practically pure iron. The first was from Swedish iron, D.V. brand, which had been remelted by Professor Arnold at the Sheffield Technical School. He accomplished this difficult feat by melting the material in a basic lined crucible and then by superheating it in the special furnace at his disposal. Before casting, 0.10 per cent. of aluminum was added. According to the analysis of the various products, the whole of the latter was oxidised. He estimated the temperature to be very high, probably over 1700° C., which was more than any of the data given in the well-known Le Chatelier experiments upon steel-melting temperatures. That experiment possessed special interest, as the whole of the experiments referred to in Professor Arnold's paper on "The Physical Influence of Elements upon Iron" were prepared from similar stock plus the different elements alloyed and the various tests, chemical, mechanical, microscopical, and physical, including recalescence observations and thermal

treatment on the iron itself, *i.e.*, without any added element, were also made upon this particular lot of material, the *modus operandi* for the production of which had been described in the foregoing paragraph. As those specimens might probably eventually be used for reference and for standards for comparison, it might not be out of place to give a detailed account of the almost pure iron, especially as that information was of importance for the purpose that the author had in view.

Professor Arnold kindly furnished him with a bar of that pure iron material, which was analysed and tested at the Hecla Works. The results were given in the following table. There were also added some tests made by him (Mr. Hadfield) three years ago, which might also be of value, as the material experimented with was raw, *i.e.*, unmelted iron exactly as received from Sweden. It was thus possible to give a comparison between the latter and similar material after remelting.

From the author's point of view, to be able to compare the properties of almost pure iron, 99.08 per cent. should be of service. The tests now given comprised, therefore, the metal—

1st. In its raw forged state.

2nd. In its raw forged state but reheated to various temperatures, cooled in water, air also, hammer hardened.

3rd. Remelted and tested in the cast state.

4th. Remelted and tested in the forged condition.

In the above cases, where referring to the remelted material, there should be little or no disturbing condition as regarded occluded gases, the remelted samples having been prepared in the crucible and out of actual contact with the gases of combustion. They should, therefore, be less influenced in that respect than if produced by other fusion processes. That was specially referred to in face of the remark by the author as to the effect of oxygen.

Tensile Strength of Pure Iron (Raw and Remelted) in Cast and Forged Conditions.

Sample.	Condi- tion in which Tested.	Description.	Mark No.	Treatment.	C.	Si.	S.	P.	Mn.	Fe.	Tensile Strength in Tons per Sq. Inch.	Specific Gravity.	Remarks.
Swedish iron, Brand LSS	Forged	{ Raw unmelted state	6	Tested as forged	.09	99.70	22.68	...	{ Evidently han- mer hardened
	...	Do. do.	7	Heated to "yel- low," quenched in water at 60° F. and reheated to "yellow"							17.90	...	
	...	Do. do.	4	Welding heat and cooled in air							19.06	...	
	...	Do. do.	8	Yellow - heated, and reheated to low red							20.82	...	
	...	Do. do.	5	Yellow heat and cooled in air							20.94	...	
	...	Do. do.	3	Low red and quenched in water							21.22	...	
	...	Do. do.	2	Yellow and quenched in water							21.28	...	
	...	Do. do.	1	Welding and quenched in water							21.55	...	
Swedish iron, Brand DV	Cast	Remelted	A	Tested as cast	0.08	0.04	0.02	0.02	0.01	99.82	20.10	...	{ Elastic limit 14.28 tons, and 16% elongation on 2 inches
Do. do.	Forged	Do.	B	Remelted and forged	0.07	0.04	0.02	0.02	0.03	99.81	21.00	7.863	{ Elastic limit 18 tons, and 60% elongation on 2 inches

As regarded the effect of oxygen, the question arose whether that element could exist free and alone in iron? Having little or no data, it was not safe to make strong statements as to this; but did it not seem more probable that that element could not exist except in combination? It was known how powerfully it acted upon iron if the latter was introduced into it in a finally divided state. Would not that action be even more marked at high temperature? It would be of special interest to actually determine that before coming to a definite conclusion, though Mr. A. Lantz, of the Peine Works, Germany, in a private communication, stated that he considered that element had a marked effect by increasing the tenacity of iron nearly one-half ton per square inch, at the same time reducing its ductility. Professor Ledebur had, he believed, contributed some investigations on this subject. The question of the presence of this element as free or in combination as a special oxide was referred to, as it might have an important bearing upon the work which Mr. Webster had in hand. Quite recently there came before the Sheffield Metallurgical Society an interesting paper by Mr. W. Galbraith "On the Presence and Influences of Oxides in Iron and Steel." That gentleman considered that there was a lower oxide which, when present, had considerable influence upon the mechanical and physical properties of steel. He also believed that "wildness" at times on basic and other steel was owing to that cause, and that "cold wild" heats, where that trouble occurred, were not due so much to lack of heat as to the extraordinary infusibility of the metal when in that state, and that that might always be concomitant with an excess of oxide of iron in the slag. He stated further that if a lower oxide was assumed, the matter became plain, because in the first place the amount of oxide for the same amount of oxygen was much larger and, if infusible, became a quantity which might evidently have an influence. He would have liked to quote that paper more fully, but hoped that the Institute might at some future time have the opportunity of hearing Mr. Galbraith's views. At any rate, with that investigation work also going on, it might be well to be cautious before accepting any evidence as to the direct effect of oxygen which really might be that of a special oxide, but none the less to be taken into account.

As regarded the effect of elements other than carbon upon iron, it would be necessary to be thoroughly safe in premises before any definite rule was formulated. He meant that the effect of a third element upon iron might be quite indirect, and although the results to the physicist might be the same, it was none the less important to have the grounds for knowledge quite clear. If not, at other times some intervening cause might be misleading. He referred specially to such an element as chromium, which without doubt worked indirectly in its action upon carbon or the carbide of iron present, and not upon the iron itself. He would, therefore, draw special attention to the extraordinary influence that the various forms of carbon, even when present in minute quantities, had brought in Professor Ledebur's various contributions, and in the recent papers to the Iron and Steel Institute by Professor Arnold and himself. It would not be safe to generalise until surer grounds were available. For example, in Professor Arnold's series, the water-quenched sample of chromium iron (carbon 0.17 per cent., chromium 1.1 per cent.) gave results quite at variance with what might have been expected. Under compression, it came next to carbon, having only shortened 20 per cent. Yet it was known almost for a certainty that, had the carbon been absent, chromium by itself would not have given any greater hardening effect than the other elements dealt with. That was clearly pointed out in his own paper, some two years ago, on the chromium alloys. Hence the indirect must not be confounded with the direct action, or, should some third cause intervene, generalisation would only be misleading. He felt very strongly convinced that it was now necessary to work out the problem of determining the exact proportions of the various forms of carbon present in any given sample of steel. That would mean, no doubt, a long and complex research, and it was from the chemist that assistance must be sought to give readier and more speedy methods of accomplishing it. Until that question was answered, investigators would continually be hampered with anomalies that contradicted and contravened each other. Judging from the various metallurgical literature, there would appear to be epochs when that question seemed to be forced particularly forward, but the important bearing of this was now more than ever apparent. Sir Frederick

Abel, Dr. Müller, and Professor Ledebur, as well as more recently Professor Arnold and Mr. A. Read, had given valuable additions to knowledge in that direction, and it now remained to work that out more fully to a satisfactory conclusion. Thanks to them and other investigators, the desired end was being approached. That reached, it was probable that many apparent anomalies and contradictory results would be made clear. The author referred to the effect of heat treatment. As he rightly stated, care should be taken to study the valuable contribution on that question by Mr. H. M. Howe, whose important paper had deserved more attention.

In order to obtain any comparison and be certain of results, the heat history of any piece of steel under examination should be fully stated. That was the more important, as since the knowledge as to the changes in form of carbon had increased, there was no doubt that slight changes in temperature had considerable influence. The particular form of carbide present considerably modified the mechanical results obtained. In fact, if such exact work as that at which the author aimed was to be satisfactorily completed, it might be found as important to understand these changes as much for a 0.10 per cent. as a 0.5 per cent. or 0.6 per cent. carbon steel. That was brought out very clearly, as those reading the paper would see, when comparing tensile tests of steel, containing 0.06 per cent. and 0.09 per cent. of carbon. Although there was only an increase of 0.03 per cent. in the latter case, the marked change in tenacity was very noteworthy. He could not conclude without complimenting the author upon his patient work. The amount of detail gone through in carrying out an investigation of that kind was exceedingly heavy. The thanks of the Institute, therefore, were especially due to him, and it was to be hoped that his reward would come in that free and full discussion of the paper which he was anxious that it should have.

Mr. A. LANZ pointed out that the investigations hitherto conducted at the Peine Works were for the most part confined to the study of the behaviour of steel containing more or less oxygen. The elaborate method of determining oxygen devised by Professor Ledebur had not permitted the experiments to be

carried out on the scale originally contemplated for conclusions to be drawn with certainty, and consequently the investigation had been for the present abandoned. He was of opinion, however, that so far he had clearly proved that as the proportion of oxygen in the steel increased, the metal lost in ductility and gained in tensile strength; it became more brittle.

Messrs. STUMM found the numerous experiments detailed in Mr. Webster's paper very interesting. In general they agreed with the views given, without, however, being able to transfer the results obtained to the ingot iron produced at other works, since the relation between the chemical composition and the mechanical figures were there independent of each other, so that one could not draw conclusions as to the unknown from the known results. In other words, similar chemical compositions did not everywhere secure similar mechanical results.

OBITUARY.

HENRY STOWE BELL died on March 15, 1894, under distressing circumstances. He committed suicide during temporary insanity, as the result of an unfounded accusation. He was a student at the Royal School of Mines from 1870 to 1873, and graduated in the metallurgical division. According to the *Times* of March 17, he was at one time in the British Consular service in Greece. He was elected a member of the Iron and Steel Institute in 1883.

ROBERT BELL died at his residence at Ratho, Midlothian, on May 30, 1894. He was the first to manufacture oil by the distillation of shale in Scotland, and was the originator of the Broxburn Oil Works, the largest works of the kind in Scotland. He was elected a member of the Iron and Steel Institute in 1889.

Sir GEORGE BERKLEY, K.C.M.G., who was born on April 26, 1821, and died on December 20, 1893, was one of the engineers to whose energy and skill the railway systems of Great Britain and the Colonies are due. After having served his apprenticeship with Messrs. Samuda Brothers, the well-known marine engineers, he was received in 1840 into the office of Robert Stephenson, where he remained until 1849, when he began to practise on his own account. He carried out important civil engineering works of a varied character. He designed Fenchurch Street Station, and widened the line of the Blackwall Railway, for which company he acted as engineer to the date of his death. He also constructed many other lines, and in 1859 succeeded Robert Stephenson as consulting engineer to the Great Indian Peninsular Railway Company. He also acted as consulting engineer for railways in Natal, Cape Colony, and the Argentine. In India, besides acting as engineer to the Indian Midland Railway, and reporting on other railways, he carried out other engineering works in various parts of the empire. From 1891 to 1892 he served as President of the Institution of Civil Engineers. He was for many years one of the Board of

Managers of the Royal Institution, and on the Queen's birthday, 1893, he was created a Knight Commander of the Order of St. Michael and St. George.

As a member of the Iron and Steel Institute, he took part in the American meeting in 1890. He made a special study of the properties of iron and steel, one of the most important of his investigations being described in a paper contributed to the *Proceedings of the Institution of Civil Engineers*, in 1870, on the strength of iron and steel, and on the design of parts of structures which consist of those materials.

JAMES COLQUHOUN died on November 20, 1893, at the age of sixty, at Weston-super-Mare. He was born at Tollcross, near Glasgow, on August 12, 1833, and served his apprenticeship with the Clyde Iron and Steel Works. In 1873 he was appointed manager of the collieries and blast-furnaces of the Tredegar Iron and Coal Company, a position he retained until his retirement in October 1892. Under his management the coalfield connected with the Tredegar Works was developed, the blast-furnaces were remodelled, the output of iron increased, and Bessemer and rolling-mill plant introduced. Mr. Colquhoun took an active interest in local affairs. He was a county magistrate for Monmouthshire; and chairman of the School Board at Bedwellty, and of the Local Board at Tredegar; he was a past-president of the South Wales Coalowners' Association and of the South Wales Institute of Engineers. He was elected a member of the Iron and Steel Institute in 1870.

Sir GEORGE ELLIOT, Bart., was born on March 18, 1815, and died on December 23, 1893, at his London residence in Portland Place. Beginning life as a pit lad, he became widely known in later years as a colliery owner. This career he entered upon in 1840, when Messrs. Backhouse and Mounsey purchased, on his advice, the Washington Colliery, near Durham—Mr. Elliot taking equal shares with them. In 1851 he resigned his appointment as chief viewer of Monkwearmouth Colliery, and became mining engineer to the late Marquis of Londonderry. In addition to his colliery undertakings, he established, in conjunction with Sir Richard Glass, important works for the manufacture of wire-rope. In 1864 the firm of Glass & Elliot was amalgamated with another and formed into the Telegraph Construction and Maintenance Company, who manufactured the second Atlantic cable much thicker and more costly than the former one. The firm afterwards became Elliot & Co., of Westminster, Cardiff, and Durham, wire-rope makers.

Sir George Elliot was a member of the Royal Commissions on Coal Supply and on Accidents in Mines, and in 1874, in recognition of his public services, he was created a Baronet. He was elected a member of the Iron and Steel Institute in 1877. He was also a member of the Institution of Civil Engineers and of the Institution of Mechanical Engineers.

RICHARD EVANS died at his residence at Consett, after a few days' illness, on April 11, 1894. He received his early training in commercial pursuits in the offices of the Dowlais Ironworks. Having acted under that firm for a long period, he was appointed to a responsible position at the ironworks at Maryport, in Cumberland, in which he discharged his duties with conspicuous ability. In 1872 he followed Mr. Jenkins to Consett, where he was acting as General Secretary to the Consett Iron Company at the time of his death. Mr. Evans was elected a member of the Iron and Steel Institute in 1878.

JOHN HICK died on February 2, 1894, at his residence near Blackburn, at the age of seventy-eight. Born at Bolton on July 2, 1815, he took when quite young an active part in the management of the Soho Ironworks. On the death of his father in 1842, he was joined in the management of the works by the late William Hargreaves. Mr. Hick filled various public positions in his native town, and represented the borough in Parliament from 1868 until 1880. During his twelve years of parliamentary life, he was frequently consulted by the Government upon subjects relating to armaments and to the construction of boilers for war-vessels. The frequency of explosions in steam-boilers induced him in 1871 to introduce a measure to provide a more efficient remedy to persons injured and property damaged by the explosions of steam-boilers through negligence. In 1874 he served on a select committee to consider the best chain cables and anchors for the navy. On his labours in connection with the improvement of steam-engines for cotton mills it is unnecessary to dwell; the work of his firm is to be found in every country where fibre is spun or fabrics woven. Mr. Hick was a member of the Institution of Civil Engineers, and of the Institution of Mechanical Engineers. He was elected a member of the Iron and Steel Institute in 1879.

FRANCIS HILL died on February 28, 1894. For thirty-two years he was a manager of Stocksbridge Works, near Sheffield, having entered

the service of the late Mr. Samuel Fox when the manufacture of Bessemer steel was first introduced. He was elected a member of the Iron and Steel Institute in 1878.

CHARLES JAMES HOMER died on November 4, 1893, at Hanley, at the age of fifty-six. Born at Hanley on August 17, 1837, he was a pupil at Earl Granville's collieries and ironworks from 1852 to 1856. In 1864 he became general manager of the Chatterley Ironstone Mines at Tunstall, and in 1871 assisted in the formation of the Chatterley Coal and Iron Company, of which he became managing director. He possessed a remarkable knowledge of the geology of the North Staffordshire coalfield, and on his advice, and with his assistance, explorations were made and collieries reopened, by which operations vast quantities of fuel were rendered available. He was one of the founders of the North Staffordshire Institute of Mining and Mechanical Engineers, of which he was president in 1874. He was elected a member of the Iron and Steel Institute in 1871.

THOMAS JOPLING, manager and director of the Otis Steel Company, died at his residence in Cleveland, Ohio, on February 18, 1894, after an illness extending over three months. He was one of the originators of the Otis Steel Company, and widely known as a business man of ability and character. Born in Northumberland on January 23, 1842, he proceeded at the age of twenty-one years to the United States, and settled in Western Pennsylvania, where he connected himself with the coal-mining industry. In 1870 he went to Cleveland, and, with Charles A. Otis, formed the Otis Steel Company, with which concern he was identified until his death. He was elected a member of the Iron and Steel Institute in 1889.

ALFRED LONGSDON died at Denmark Hill, London, on November 27, 1893, at the age of sixty-seven. He was born on May 22, 1827, and entered the service of Mr. Alfred Krupp of Essen in 1855. In 1865 he was appointed the firm's representative for Great Britain, and in 1873 became one of the directors. In that year, on behalf of the Essen firm, he took part in the formation of the Orconera Iron Ore Company, of which he was managing director in London. He was one of the original members of the Iron and Steel Institute, and on his death bequeathed to the Institute a valuable marble bust of Alfred Krupp.

DANIEL MACNEE died on June 30, 1893, at the age of fifty-five. Son of Sir Daniel Macnee, President of the Royal Scottish Academy, he was born in Glasgow on April 23, 1838. After serving an apprenticeship as a mechanical engineer and a pupilage as a civil engineer, he was engaged on the construction of various branch lines of railway. In 1864 he entered the service of Messrs. Charles Cammell & Co., of Sheffield, as their engineer. In 1869 he joined the firm of Messrs. Joseph Armstrong & Co., of Rotterdam, manufacturers of railway ironwork. In 1877 he began practice as an engineer at Rotterdam, and laid out several important works. In 1879 he designed and built the railway points and crossing department of the Anderston Foundry Company's works at Port Clarence, near Middlesbrough. He was acting as representative of that company in Westminster at the time of his death. He was a member of the Institution of Civil Engineers, and of the Institution of Mechanical Engineers. He was elected a member of the Iron and Steel Institute in 1881.

JOSIAH J. RICHARDS, who died on May 19, 1894, filled for seventeen years past the responsible position of manager of the Bessemer and open-hearth departments of the Atlas Works at Sheffield. He began his career at the Ebbw Vale Steelworks, and was subsequently successful in developing the manufacture of Bessemer steel at the Dowlais Works. He afterwards held for about seven years the position of manager at Ebbw Vale Steelworks, and in 1877 he was appointed manager of the Bessemer department of Messrs. John Brown & Co. He was one of the original members of the Iron and Steel Institute.

ROBERT ROPER died on January 21, 1894, at the age of forty. Early in life he held an appointment at the Sheffield and Hallamshire Bank. In 1881 he resigned his position there, and was appointed Secretary of the Sheffield Forge and Rolling Mills Company. He was elected a member of the Iron and Steel Institute in 1891.

JOHN ROGERSON, who died in London on February 6, 1894, was widely known in the iron and coal trades. He was practically a self-made man. Born at Morpeth in 1828, he began his career as a clerk in the office of the Northumberland and Durham Coal Mining Company. He afterwards became the agent for Messrs. Longridge & Co., of the Bedlington Ironworks, and for Messrs. Joseph Cowan & Co., of Blaydon Burn. He also acted as fitter for Barrington Colliery, and for Cowen's

Garesfield Coal and Coke Co. He was fortunate enough to make some investments in shipping shortly before the Crimean war. These investments turned out to be highly successful, and led to his becoming considerably interested in shipping property. Between the years 1856 and 1859 the great development of railways in the United States created a heavy demand for iron and railway plant. Mr. Rogerson visited America at the time, and made important contracts with some of the railway companies. These contracts were fulfilled, but the civil war broke out before the railways were completed, and a good deal of the iron was used for military purposes. On the resignation of the late Mr. Charles Attwood from the direction of the Weardale Iron and Coal Company, Mr. Rogerson succeeded him, and was for several years the manager of that company. On the death of Mr. Attwood, Mr. Rogerson became owner of that gentleman's private ironworks at Wolsingham. To the improvement and development of these works he gave great attention. He was a shareholder in nearly all the larger mercantile concerns in the North of England, and a director of some. He was elected a member of the Iron and Steel Institute in 1870.

DANIEL WHITEHOUSE died at Newport on April 10, 1894, at the age of sixty-eight. He was the proprietor of the Abercarn and Macher Tinworks, and amassed a considerable fortune. Within the last two or three years, however, the works at both places suffered in consequence of the depression in the tinplate trade, and many of the hands were discharged, until at length the works were closed altogether. Mr. Whitehouse was a self-made man, and was in early life employed in one of the establishments which afterwards became his own. He was elected a member of the Iron and Steel Institute in 1881.

ADDITIONS TO THE LIBRARY

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“Natural Science at the Chicago Exhibition.”	F. A. Bather, M.A.
“The Mines Statement of New Zealand.”	The Minister of Mines.
“Le Cuivre.” By Paul Weiss.	J. B. Baillière & Fils (publishers).
“Eleventh Report of the State Mineralogist of California, Sacramento, 1893.”	J. J. Crawford.
“Transactions of the New York Academy of Sciences.” Vol. xii.	The Academy.
“Annals of the New York Academy of Sciences.” Vol. viii.	The Academy.
“Stahl und Eisen.” Jan. to June 1884.	Dr. E. J. Ball.
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“Official Year-Books of the Scientific and Learned Societies of Great Britain and Ireland.” 1889 to 1893. (Five Volumes.)	Bennett H. Brough.
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"Paper on the Desulphurising of Iron and Steel." By E. H. Saniter.	The Author.
"Blast-Furnace Practice at Ormesby Iron Works, Middlesbrough."	C. Cochrane.
"The Iron Industry—What it is to Great Britain and the United States—What it may be to Canada."	The Canada Iron Furnace Co., Limited.
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"Rapport concernant les expériences exécutées par MM. Ludwig & Weber sur la batterie des chaudières, &c."	M. M. Kullman & Cie.
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"Notes on the Efficiency of Gaseous Fuel." By F. A. Matthewman.	The Author.
"Iron Ore Deposits of Dunderland, Norway."	Ivar Lagerwall.

INSTITUTIONS.

The Publications of the Institute are exchanged for those of the following Institutions :—

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COLONIAL AND FOREIGN.

Colonial:

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 Canadian Society of Civil Engineers.
 Department of Mines, Sydney.
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 Geological Survey of Canada.
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United States.

American Association for the Advancement of Science.
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School of Mines, Columbia College, New York.
Smithsonian Institute.
United States Geological Survey.

Austria.

K. k. geologisches Reichsanstalt.
Oesterr. Ingenieur und Architekten-Verein.

Belgium.

Ministère de l'Interieur.

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Comité des Forges.
Le Ministère des Travaux publics.
"Revue Maritime." Ministère de la Marine.
Société d'Encouragement pour l'Industrie Nationale.
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Denmark.

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Germany.

Königliche Bergakademie in Freiberg.
Königliche Technische Versuchsanstalt.
Verein Deutscher Eisenhüttenleute. (Journal "Stahl und Eisen.")
Verein Deutscher Ingenieure.

Italy.

Ministero di Agricoltura.
Reale Accademia dei Lincei.
R. Comitato Geologico d'Italia.

Japan.

Department of Mines.

Sweden.

Jernkontoret.

JOURNALS.

The following periodicals have been presented by their respective Editors :—

UNITED KINGDOM.

"British Trade Journal."
"Coal and Iron."
"Commerce."
"Contract Journal."
"Colliery Guardian."
"Electrician."
"Electrical Plant."
"Electrical Engineer."
"Engineer."
"Engineer and Iron Trades Advertiser."
"Engineering."
"Engineering Review."
"Hardware Trade Journal."
"Industries and Iron."
"Iron and Steel Trades Journal."
"Iron and Coal Trades Review."
"Ironmonger."
"Ironmongery."
"Iron Trades Circular."
"Invention."
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"Plumber and Decorator."
"Practical Engineer."
"Railway Engineer."
"Railway World."
"Shipping World."
"Statist."
"Steamship."
"Transport."

COLONIAL AND FOREIGN.**Colonial.**

"Canadian Mining Review."
"Indian Engineer."
"Indian Engineering."

United States.

- "Age of Steel."
- "American Journal of Science."
- "American Manufacturer."
- "Bradstreet's."
- "Cassier's Magazine."
- "Colliery Engineer."
- "Engineering and Mining Journal."
- "Engineering Magazine."
- "Engineering News."
- "Iron Age."
- "Railroad Gazette."

Austria.

- "Oesterr. Zeitschrift für Berg- und Hüttenwesen."

Belgium.

- "Association des Ingénieurs de Liège."
- "Association des Maîtres des Forges de Charleroi."
- "Bulletin de l'Union des Charbonnages de Liège."
- "Moniteur des Interêts Matériels."
- "Revue Universelle des Mines."

France.

- "Annales des Mines."
- "L'Echo des Mines."

Germany.

- "Annalen für Gewerbe und Bauwesen."
- "Chemiker Zeitung."
- "Zeitschrift für das Berg-, Hütten- und Salinenwesen im preussischen Staate."
- "Verein Deutscher Eisen und Stahl Industrieller."

Italy.

- "L'Industria."

Norway.

- "Teknisk Ugeblad."

Spain.

- "Revista Minera."

Sweden.

- "Teknisk Tidskrift."

SECTION II.

*NOTES ON THE
PROGRESS OF THE HOME AND FOREIGN
IRON AND STEEL INDUSTRIES.*

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IRON ORES.

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I.—OCCURRENCE AND COMPOSITION.

Iron Ore in Ayrshire.—J. Smith * describes a bed of ironstone occurring in the parishes of Dalry, Stevenston, and Kilwinning in Ayrshire. The bed appears to be entirely embedded in tuff, and seems to have had its origin in showers of fine dust from some neighbouring volcano, which had settled down in quiet water. As far as the investigations have been carried, there appears to be no trace of drifted material from a land surface. From analysis, the raw ore contains about 26 per cent., and the calcined material 41 per cent. of iron. The bed is $4\frac{1}{2}$ feet in thickness.

The Iron Ore Measures of County Antrim.—According to G. H. Kinahan,† the iron ore measures are a subordinate group in the Eocene dolerites of County Antrim, and, when fully represented, consist of the following members :—

1. Lithomarge.
2. Ochreous rock. (*Pavement.*)
3. Bole or aluminous ore. (*Second ore.*)
4. Pisolithic or pebble ore. (*First ore.*)
5. Steatitic rock. (*Brushing.*)
6. Steatitic clay. (*Holing.*)
7. Alumite.
8. Lignite.

* Paper read before the Geological Society of Glasgow, *Industries and Iron*, vol. xvi. p. 22.

† *Transactions of the Manchester Geological Society*, vol. xxii. pp. 458-466.

The iron ore measures appear to have been in part lacustrine deposits, which accumulated in shallow lakes or ponds, in hollows on the ancient surfaces of the lava sheets, to be subsequently covered up by newer sheets of lava. The author is of opinion that the iron ores are secondary adjuncts of the lake accumulation, as they accumulate at a subsequent period as a true lode in a horizontal shrinkage fissure, the filling being from below upwards, and not from wall to wall, as in a vertical lode. The lower deposits are more or less impure, whilst the highest one was richest in metal.

The Bennisch Iron Ore Mines.—F. Kretschmer * observes that even in the Middle Ages these mines had been long at work. In recent years they have been worked chiefly in connection with the Witkowitz Ironworks. The Moravian Silesian Devonian formation has its greatest thickness at Römerstadt-Hof. At the north it rests on the gneisses and metamorphic schists of the Hohe-gesenke, and in the south, on the granite-syenite mass of Adamsthal and Blansko. It is overlain by grauwacke-sandstones of the culm formation. The general geological character of the district is considered, and the various iron ore mines in the field are then briefly described. In the Randenberg mines the ore deposit is found in an amygdaloidal diabase. At the outcrop, brown iron ore of a very soft character is found, while with depth the hardness and compactness increase, and the brown iron ore gives place to magnetite. The ore deposit is a large one, but water occurs in quantity, rendering mining difficult.

The Spachendorf-Raase mines are next considered. Two deposits of iron ore are known in this district. One of these, like the deposit just described, occurs in amygdaloidal diabase, together with limestone, and in places clay slate. The ore is magnetite, and occurs in the form of a series of lenticular masses. The second ore deposit occurs immediately above a limestone bed.

The ore has the following composition :—

Magnetic Oxide of Iron.	Silica.	Alumina.	Lime.	Magnesia.	Loss on Ignition.
48·80	18·70	2·30	10·39	0·50	19·31

At the Bennisch group of mines, the ore occurs below a bed of Schalestein, but the geological character of this district is somewhat varied. The ore near the surface is chiefly a brown hæmatite, derived from magnetite, which occurs in depth. Three ore beds are being worked.

* *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlii. pp. 167-175 and 186-188.

Analyses are not given except in the case of magnetite from the Seitendorf mines. This contained :—

	Per Cent.
Ferric oxide	8·70
Ferrous oxide	41·53
Manganese oxide	0·40
Silica	8·17
Alumina	2·60
Lime	21·50
Magnesia	1·07
Sulphur	0·28
Phosphoric anhydride	0·84
Carbonic anhydride	16·10
Total	101·19

Different parts of the ore deposit at these mines are separately described, although in reality there is only one deposit. The ore varies considerably in appearance, the upper portion of the bed being usually red, while the lower part consists of black unaltered magnetite.

The Iron Ores of the Eastern Pyrenees.—According to E. Fuchs and L. de Launay,* the Canigou Range forms the eastern continuation of the Pyrenees. It is a mass of granite rising steeply from the plain of Perpignan to a height of some 9000 feet. On the northern slope are quartzose Silurian slates, interpolated with beds of sandstone and metamorphosed conglomerate, and with softer micaceous slates, and limestones. At the base of the main range is another, less than half its height, which consists of clay slates and limestones. As a rule it is this minor range in which the iron ore deposits are found. The beds are considerably faulted. The ore is either a spathic carbonate with some pyrites, or one of the oxides, and usually the hydrate. These iron ores are found mixed, and in all kinds of intermediary stages. Not only the carbonate ore but also the oxide contains manganese. It would appear that in the deep the carbonate is the chief ore. The ores contain :—

Fe.	Mn ₂ O ₄ .	CaO.	Al ₂ O ₃ .	SO ₃ .	P ₂ O ₅ .	SiO ₂ .
46·0-64·8	0·0-9·2	0·0-3·4	0·0-10·5	0·0-0·16	0·0-0·12	2·0-11·5

There are three main deposits worked—those at Batère, Prades, and Puymarens. In the Batère district there are four main limestone beds, which are intersected by five or six veins of iron ore of considerable extent. The ore filling is manganiferous spathic ore. At the Ballestang mine an almost vertical lode is worked, varying from 5 to over 20 yards

* *Traité des Gîtes Minéraux et Métallifères*, Paris, 1893, vol. i. pp. 677-685.

in width, half this width being iron ore containing 52 per cent. of iron. Other wide veins are worked at the Pinouse and Sarraz-Magré mines. In the Pinouse mine the main vein occasionally reaches a thickness of as much as 240 feet. The ore is a rich mangiferous brown ore, with some spathic ore.

At the Prades mine three groups of veins are known, extending for 8 or 9 miles in length. At the South Escaro mines the ore is found between a hanging wall of limestone and a foot wall of slate. They are as much as 30 to 40 yards in width. At the North Escaro mines five veins of similar size are worked, the Aytza ore being highly mangiferous. Other large deposits of ore are also mentioned. The iron ore is occasionally accompanied by galena poor in silver.

Recent Discovery of Iron Ore.—At a depth of from 60 to 70 yards, near the village of Hüttenrode in Brunswick, Germany, a bed of iron ore has been discovered which has already been proved to a thickness of 13 yards. It consists of a calcareous hæmatite, together with magnetite and brown iron ore. An analysis is not given. *

The Iron Ore Deposits of Elba.—According to Fuchs and De Launay,† the larger iron ore mines on the east coast of Elba are, from north to south, the Rialbano, Rio, Terra-Nera, and Calamita. The ore is chiefly specular iron ore, with hæmatite, which has not yet been mined, and small quantities of magnetite. The ore deposits appear to be neither lodes nor beds, but rather surface deposits which rest on the older slates, or occur in hollows in limestone. In the Rio mines the ore has replaced the lower Lias limestone, and rests on Permian carboniferous slate. At Rialbano and Calendorio the ore deposits rest on the Permian and on the lower Lias, but at Calamita and Terra-Nera on Cambrian beds. It has been observed that these deposits are in some way connected with the orographic structure of the vicinity, which shows that they are of recent formation. If the ore replaces limestone, it is purer than when found resting on slates. As a rule, it is found that the ore occurs with slate as a foot wall, and with limestone as the hanging wall, while occasionally the ore is in the midst of limestone. The ore is accompanied by iron-calcium silicates, metamorphic derivatives of the original older limestones, and not, as has been assumed, of eruptive origin. It is very possible that the ferruginous water from which this ore resulted

* *Stahl und Eisen*, vol. xiv. p. 240.

† *Traité des Gîtes Minéraux et Métallifères*, vol. i. pp. 808-814.

was formed originally in the deep, and passed through the limestone before reaching the surface.

The largest but least known deposit is that of Albano. It was not worked by the ancients, and is now only worked at one spot, near the coast. The ore forms a surface deposit with an average thickness of about eleven yards, though in places it is five times as thick as this. It covers a superficies of 6,996,800 square feet. At the Pestello mine, the ore occurs as an isolated pillar between Permian conglomerate and the Lias; at Poppajo, however, it is found in the form of veins and beds in the Lias slate, which in turn rests on Permian beds. The Rio and Vigneria deposits were largely worked by the ancients. The latter is now nearly exhausted. As a rule, in all these deposits the percentage of iron varies from 58 to 62. The following are partial analyses of ore from the mines named:—

	Rio.	Terra-Nera.	Calamita.
Iron	61·81	62·12	63·87
Silica	5·97	3·65	3·28
Sulphur	0·17	0·11	0·32

Phosphorus was present in quantities varying up to 0·008 per cent.

These Elba deposits were worked in the most remote antiquity. A royalty of 5s. 6d. per ton of ore mined is paid to the Italian Government. The output of ore has been as follows:—From 1831 to 1881, 3,430,000 tons, the quantity raised in 1880 having been 600,000 tons. Since that date, the output has been limited to about 200,000 tons a year. In 1885, Fabri estimated the remaining ore at about 8,000,000 tons; 2,000,000 each at Rio, Rialbano, and Calamita, and half this quantity at Lavato and at Paletta. The cost of mining and shipping varies from 1s. 6d. to 4s. per ton.

The known quantity of iron ore existing in the Island of Elba is now estimated at about 6,200,000 tons. Analyses showed the ore to contain from 61·81 to 63·87 per cent. of iron; from a trace to 0·22 of manganese; 3·283 to 5·970 per cent. of silica; 0·113 to 0·321 per cent. of sulphur; and from 0·000 to 0·008 per cent. of phosphorus.*

The Iron Ores of Krivoirog, Russia.—According to Fuchs and De Launay,† Krivoirog lies on the borders of the provinces of Ekaterinoslaff and Kherson, at the junction of the Saxagana and Inguletz

* *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xli. p. 567.

† *Traité des Gîtes Minéraux et Métallifères*, vol. i. pp. 738–742.

rivers. It is the centre of this iron ore district. The district itself consists of a deforested plain, scored in places by a series of gullies or cañons, in which the beds of iron ore are visible. Up to 1881 they were practically unworked. The southern portion of Russia, between Odessa and Charkcoff, consists of granitic or syenitic rocks, covered as a rule by clays, sands, or limestones. At Krivoirog, Silurian slates and quartzites fill a basin in the granite, some $5\frac{1}{2}$ miles wide and 20 miles in length. These beds contain stockworks of iron ore, schistose specular ore, red and brown hæmatites, and especially an oxidised magnetite. At the point of contact the quartzites are often coloured strongly, and contain up to 15 per cent. of iron. Four lenticular beds are known. The ore is of very varied character. The gangue is usually quartzose in character, and this is most especially the case with the schistose specular ore, which is frequently so acid in character as to more particularly resemble a quartzite impregnated with iron ore. In the anhydrous ores, phosphorus and sulphur are present only in infinitesimal traces, whilst the hydrated ores only occasionally contain as much as 0·001 per cent. of phosphorus. Three analyses showed :—

	Per Cent.	Per Cent.	Per Cent.
Iron	67·420	65·830	59·090
Silicon	1·130	3·260	11·620
Aluminium	1·340	2·840	3·710
Sulphur	0·018	0·015	0·014
Phosphorus	0·033	0·030	0·038

The ores yield in the blast-furnace about 55 per cent. of iron. Hitherto they have been mined open-cast. Using explosives, 100 workmen raise about 200 tons. Another similar deposit exists in the same neighbourhood, in the Berdiansk district. The ore is magnetite, and it occurs as a stockwork between quartzites and crystalline slates. These ore deposits are comparatively close to the great Donetz coal basin.

The Iron Ores of the Ural.—According to Fuchs and De Launay,* on the eastern slopes of the Urals a number of iron ore beds are known. The largest is that of Visokaja-Gora, near Nijnitagilsk. These are treated in blast-furnaces belonging to the local government. In the whole of the central Urals there is a remarkable connection between the deposits of iron and copper. Not only do the iron ores contain traces of copper pyrites, but there are nearly always important deposits of the oxidised ores of copper in the vicinity of the iron ore bodies. The iron ores occur in syenite in the vicinity of a band of Silurian limestone, and are in the form of a stockwork, the ore being a more

* *Traité des Gîtes Minéraux et Métallifères*, vol. i. pp. 664-671.

or less oxidised magnetite, occurring as martite. The ore seems to form a thin coating on the side of a mountain. It is porous, soft, and very easily reduced in the furnace. An analysis showed:—

Fe_2O_3 .	Fe_2O_3 .	Mn_2O_3 .	CaO.	Al_2O_3 .	SiO_2 .
16.71	74.09	2.84	0.40	2.86	2.60

Sulphur and phosphorus occur in very varying quantities in this ore, as copper pyrites and apatite. Sometimes only traces are present, while at other times it is nearer 1 per cent. Vanadium is always present in these ores, and is concentrated in the slag from the Franche-Comté hearth to 0.06 per cent.

The Iron Ores of Dannemora.—The Dannemora deposit is said by Fuchs and De Launay * to have been worked in the thirteenth century. The output of ore is annually about 35,000 tons, and this is mined by 100 workmen. The ore deposit is a series of lenticular bodies in a band of limestone, surrounded by granites, diorites, and gneiss, and enclosed in a mass of hälleflinta. This is a grey material of porphyritic appearance, and consists of a dense siliceous ground-mass, in which quartz grains are visible. The iron ore deposit as mined is about 200 yards broad and 2000 long. The mine is about 650 feet in depth, and the deposit is still unchanged, either in size or richness. An examination of these lenticular ore bodies shows that they are arranged in three systems, separated from each other by hälleflinta. The largest and oldest deposit is in the second series. This does not consist wholly of ore, but partly of limestone as well. The ore consists of magnetite which in the southern portion of the deposit has a calcareous gangue, whilst in the northern portion the gangue is a garnetiferous amphibole. It is always of a finely granular structure. The following are analyses of ore: I. From the northern portion of the ore field; II. From the central portion; and III. From the southern deposits:—

Description.	I.	II.	III.
	Per Cent.	Per Cent.	Per Cent.
Magnetic oxide of iron	65.860	71.650	72.250
Ferrous oxide	1.450	0.710	1.500
Manganous oxide	0.890	2.230	2.050
Magnesia	4.540	5.660	4.140
Lime	7.620	5.200	5.500
Alumina	1.080	1.490	2.600
Silica	15.320	9.300	8.900
Phosphoric anhydride	0.002	0.005	0.009
Sulphur	0.171	0.027	0.038

* *Traité des Gîtes Minéraux et Métallifères*, vol. i. pp. 714-719.

A breccia often occurs in the neighbourhood of the ores, which consists mainly of amphibole very rich in manganese, one analysis showing 8·46 per cent. of manganous oxide, together with 38·21 per cent. of ferrous oxide, and 48·89 per cent. of silica, amphibole being in admixture with pyroxene. The ores are comparatively high in sulphur, and consequently require roasting. The sulphur is mainly in the form of pyrites; but both the basic and acid ores are sulphurous. The pyrites sometimes occurs in isolated crystals, and sometimes in the form of narrow stringers.

The Iron Ores of Norberg, Sweden.—The Norberg iron ore mines are in the north-eastern portion of the Province of Westmanland, and, according to Fuchs and De Launay,* they are the most important iron ore mines in the whole of Sweden. They were worked as far back as the fourteenth century. In the years 1870 to 1879 the average annual output was 100,000 tons, but in 1892 this output had sunk to 52,982 tons. Zones of mica schist, eurite, and dolomite course from north-east to south-west, and in the south they are bordered by a mass of red granite containing no mica. The eurites or leptinites are felspathic rocks, which may be compared with bedded granulites. The iron ores are found in the leptinites and in dolomite, being quartzose in the one case and basic in the other. They occur in stockworks trending in approximately a straight line. This is five miles in length, and in 1892 was being mined at seventeen points. The ores are of three kinds:—

1. Dry ores, mostly hæmatite, with about 20 per cent. of quartzose gangue. In 1892, 8915 tons of this ore was mined, or about 16·8 per cent. of the total quantity of ore. On the average these ores contain:—

	Per Cent.
Ferric oxide	35·71
Ferrous oxide	33·13
Manganous oxide	0·15
Magnesia	0·13
Lime	6·20
Alumina	0·50
Silica	21·80
Phosphoric anhydride	0·61
Sulphur	0·08
Copper	traces
Moisture and loss	1·69
Total	100·00

* *Traité des Gîtes Minéraux et Métallifères*, vol. i. pp. 708-712.

2. The second class of ore consists of the lime ores, mostly magnetite, with dolomite gangue, and often rich in manganese. In 1892, 30,079 tons of this class of ore was mined, 56·7 per cent. of the total quantity of ore raised. An analysis of this ore showed :—

Fe_2O_3 .	MnO.	MgO.	CaO.	Al_2O_3 .	SiO_2 .	Loss on Ignition.
70·00	10·40	1·05	1·20	2·05	1·13	15·00

3. The third class of ore is termed "black ore," and has a pyroxene gangue. The quantity of this ore raised in 1892 was 13,987 tons, or 26·5 per cent. of the total quantity of ore mined. A sample of this ore had the following composition :—

	Per Cent.
Ferric oxide	3·57
Ferrous oxide	63·80
Manganous oxide	0·23
Magnesia	5·26
Lime	8·60
Alumina	0·16
Silica	18·60
Phosphoric anhydride	0·09
Sulphur	0·45
Copper	traces
Total	100·76

The deposits of dry or quarry ore occur generally nearest the granite. They are really an iron gneiss in which iron glance has replaced the mica. This iron ore deposit is undoubtedly of great age.

The Blackbergfeld deposit is typical of the lime ores. The ore in this case occurs as a lenticular deposit in dolomite, which, again, is enclosed in eurite. The ore is nearly solid magnetite with some 10 per cent. of manganese and 2 of graphite, often concentrated in small veins. Graphite is also found in the calcareous ores of Kolnengsberg. Traces of pyrites or of other sulphides are of rare occurrence, being only found occasionally. Those ores, too, which have pyroxene gangue also occur in leptinite. Magnetite is the most frequent ore in this case, and it occurs bedded in conjunction with green chlorite and amphibole.

The Routivare Iron Ore Deposit.—According to W. Petersson,* the Routivare iron ore deposit is situated about nine miles from Quick-jokk in the Swedish province of Norrbotten. The ore consists of titaniferous magnetite, associated with green spinel, olivine, and talc. The rock in which the ore occurs is a highly altered gabbro. The ore, to which the name of magnetite-spinellite is assigned, occurs, sharply

* *Geologiska Föreningens Förhandlingar*, vol. xv. pp. 45-54.

defined from the enclosing rock, as enormous brecciated masses. Analysis of the ore (I.), and of the enclosing rock (II.), gave the following results:—

	SiO ₂ .	TiO ₂ .	Al ₂ O ₃ .	Cr ₂ O ₃ .	Fe ₂ O ₃ .	FeO.	MnO.	MgO.	CaO.	K ₂ O.	Na ₂ O.	H ₂ O.	P ₂ O ₅ .
I.	4·08	14·25	6·40	0·20	33·43	34·58	0·45	3·89	0·65	0·15	0·29	1·32	0·016
II.	47·37	0·25	23·22	0·39	...	6·42	0·28	8·67	6·86	0·63	3·25	3·25	...

H. Sjögren * has also described this iron ore deposit. He found in the ore the following constituents:—(1) titaniferous magnetite, the main component; (2) ilmenite; (3) spinel; (4) olivine; (5) pyroxene; (6) chlorite; and (7) as accessory constituents, magnetic pyrites and apatite. The enclosing rock is classed as gabbro, or gabbro-diorite.

Iron Ore in New South Wales.—J. E. Carne † reports on the principal known iron ore deposits, adjacent to the railway line, in the neighbourhood of Lithgow, Newbridge, Blayney, and Lyndhurst. He gives the following analytical results:—

Description.	I.	II.	III.	IV.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Moisture	8·47	5·10	5·30	0·13
Silica	37·80	66·80	63·43	6·50
Alumina	5·89	19·84	24·55	14·22
Ferric oxide	46·11	7·53	6·02	60·48
Ferrous oxide . . . . .	...	...	...	18·67

I., II., III., are analyses of samples from two new bands of clayband iron ore, discovered in 1883 on the Eskbank Iron Company's property. I. gave a return equal to 33·1 per cent. of iron, but II. and III., representing the bulk of the bands, proved to be clayshales, impregnated to a small extent with ferric oxide. IV. shows the character of an important deposit of iron ore found on Cowriga Creek, near Blayney.

The occurrence of iron ore associated with limestone, in Parish Calvert, renders it extremely probable that a good supply will be found. In the parish of Walli, in the county of Bathurst, a large lode of brown iron ore has been found, and at Newbridge there is a deposit of brown iron ore of good quality. The Newbridge deposit appears to be an

* *Geologiska Föreningens Förhandlingar*, vol. xv. pp. 55-63, 140, 143.

† *Annual Report of the Department of Mines*, New South Wales, Sydney, 1893, pp. 147-150.

abnormal thickening in a fissure that courses across the country for several miles. A further examination may possibly reveal the occurrence of other similar bunchy deposits.

J. E. Carne * also describes the chrome iron ore deposits near Coolac, in county Harden. The ore yields 47 to 52 per cent. of chromic oxide. A second group of deposits of a similar character occur six miles distant, on the Murrumbidgee River.

Iron Ore Deposits in Victoria.—The Nowa Nowa arm of Lake Tyers, Victoria, terminates about five or six miles from the ocean. Here tertiary beds make contact with upturned Silurian slates, and intrusive masses of felsite porphyry also occur. Masses of jasper and of hæmatite are of frequent occurrence, and on one hill a patch of about an acre in extent consists of extremely pure micaceous iron ore. The ore has not as yet been worked, but phosphorus is usually entirely absent, and sulphur is stated to occur only in traces.†

Iron Ore in Canada.—R. G. M'Connell ‡ reports that clay ironstone, in nodules and thin beds, is of general occurrence in the Cretaceous shales of the Athabasca district, but is especially abundant in some of the outcrops of the Fort St. John shales on Peace River. Owing to the rapid erosion of the soft shales, the ironstone has been silted out, and in many places forms thick accumulations at the foot of the cliffs lining the valley, some of which may prove of economic value. The sandstone is usually capped with a bed of hæmatite bearing sandstone, varying from a few inches up to 5 feet and containing 12·4 per cent of iron.

Reporting on the geology of the counties of Portneuf, Quebec, and Montmorency, A. P. Low§ states that deposits of bog iron ore have for a long time been worked in the vicinity of Three Rivers, where it has been smelted in the St. Maurice Forges. On the St. Louis road, about four and a half miles from Quebec, there is a small deposit of bog manganese ore.

According to H. Fletcher,|| mining operations have been vigorously begun on a vein of limonite which lies at the contact of the carboniferous and pre-carboniferous rocks on the north bank of the East River of

* *Annual Report of the Department of Mines, New South Wales, Sydney, 1893*, pp. 153-159.

† *Australian Mining Standard*, vol. ix. p. 453.

‡ *Annual Report of the Geological Survey of Canada*, vol. v. Report D.

§ *Ibid.*, Report L.

|| *Ibid.*, Report P.

Pictou. By the New Glasgow Company, a railway thirteen miles in length has been constructed, and blast-furnaces and coke-ovens have been built. By another, the Pictou Charcoal Iron Co., the excellent ore on the Grant farm at Bridgeville is being prospected. Other important deposits of iron ore in the counties of Pictou and Colchester are fully described.

In a report on the work done in the laboratory of the Geological Survey, G. C. Hoffmann * gives the results of analyses of six specimens of magnetite from Ontario, and of three specimens of hæmatite from Ontario and Nova Scotia.

The occurrence of nickel ore at the Sudbury mining district, visited by the Iron and Steel Institute in 1890, is fully described by R. Bell.†

Canadian Lake Iron Ore.—J. G. Donald ‡ points out that lake iron ore, similar to that occurring in Sweden and Finland, is worked in Canada. The principal source is the Lac à la Tortue, in the St. Maurice district.

Dr. Percy's description of the Swedish lake ore is fully applicable to the Canadian occurrence. The composition of the ore is as follows:—

Fe ₂ O ₃ .	Mn ₂ O ₃ .	Al ₂ O ₃ .	CaO.	MgO.	P ₂ O ₅ .	SO ₂ .	SiO ₂ .	Loss on Ignition.	Total.
70·04	1·78	2·20	0·32	0·27	0·76	0·23	7·84	16·84	100·28

The percentage of iron is 49·03, of phosphorus 0·331, and of sulphur 0·093.

Iron Ore in the Tenasserim Valley.—In reporting on the geology of a part of the Tenasserim Valley, P. N. Bose § points out that lateritic iron ores are widely distributed in the valley. They are, however, superficial deposits, and do not appear to be rich. Samples examined contained 36·06 to 50·49 per cent. of iron, but the average ores are far inferior.

Close to the mouth of the Tenasserim, however, there are extensive deposits of similar ore at Maha Champa. The average percentage of iron is 36·8. The boats which would carry coal from the Tendau-Kamapying field down to Mergui could take up the iron ore. If therefore this coal should be worked, it would be advisable to make a fair trial

* *Annual Report of the Geological Survey of Canada*, vol. v. Report R.

† *Ibid.*, Report F.

‡ *Engineering and Mining Journal*, vol. lviii. p. 250.

§ *Records of the Geological Survey of India*, vol. xxvi. pp. 161-163.

of the Maha Champa ore. The limestone ridges in the vicinity of Therabwin would supply excellent flux.

The Ore Deposits of the United States.—In a volume covering 302 pages and provided with 67 illustrations, J. F. Kemp* supplies a condensed account of the metalliferous resources of the United States. A complete bibliography of the subject is given, and to the descriptions given by others, the author has added observations made by himself in travel during the last ten years. A few general conclusions suggest themselves from his investigations. The extreme irregularity in shape of metalliferous deposits shows the unsatisfactory nature of the United States law of the apex, which is based on well-defined fissure veins. Secondly, the very general proximity of eruptive rocks to the ore-bodies seems to indicate that these rocks were important factors in the circulations that formed the ores. Lastly, the choice is open whether it is better to refer the ore to original dissemination in the dark silicates of many rocks shown by Sandberger to contain percentages of metals, and to derive it by gradual concentration probably at great depths, or to refer it to some indefinite unknown source below.

Sixty pages of the volume are devoted to descriptions of American occurrences of iron ore.

Iron Ore in Alabama.—W. B. Phillips † describes the geological formation and the iron ore deposits of Murphree's Valley, which is a continuation of Jones' Valley, in which Birmingham is situated. The red Clinton or fossil iron ore, limonite, and mountain limestone are worked. The Clinton formation is about 150 feet in thickness, and lies conformably on the Trenton limestone. The best ore carries 50 per cent. of iron, and less than 0·3 per cent. of phosphorus, but other ore contains as much as 5 per cent. At the Compton mines, the ore was formerly worked open-cast. The brown ores occur in six horizons, only the lowermost being worked, one mine in this deposit giving ore yielding 56 per cent. of iron in the furnace. Open-cast workings have been carried to a depth of sixty feet, but the deposits appear to be somewhat irregular. The amount of ore obtained on washing the material ranges from 5 to 25 per cent. of the total.

Iron Ore in California.—W. Irelan ‡ describes the condition of

* *The Ore Deposits of the United States.* New York, 1893.

† *Engineering and Mining Journal*, vol. lvi. pp. 448-449.

‡ *Eleventh Report of the State Mineralogist of California.* Sacramento, 1893.

the iron ore mining industry of California. In Fresno county, the Minaret iron mines, of which photographs are given, offer a practically inexhaustible supply. In Marin county, iron and manganese ore occur in considerable quantities in San Geronimo township. In San Bernardino county, there are the largest deposits of iron ore on the Pacific coast. They are situated sixteen miles from Newberry station, and consist of hæmatite and magnetite. Notwithstanding favourable reports on the character of the ore, the deposits have not yet been opened up. From the Stillwater district of Shasta county, there has lately been shipped a truckload of iron ore to the Pacific Rolling Mills. This ore contains 72 per cent. of iron. In Tulare county, a large deposit of bog iron ore is reported on the middle fork of the Tule river.

The Biwabik Iron Mine, Mesabi Range, Minnesota.—According to Winchell and Jones,* the ore-body is half a mile long, nearly a quarter of a mile wide, and of a thickness of 100 feet. It has been prospected by 23 shafts in ore; one drift or level extended to a distance of 50 feet south, and one drift 150 feet to the north-east from pit No. 15, and several drill-holes from the bottom of the shafts. The cubic contents of the deposit are given as 247,155,000 feet, or, taking 11·9 cubic feet to the ton, 20,769,329 tons. The average analysis of each grade of ore is given as:—No. 1, iron, 60·04; phosphorus, 0·026; No. 2, iron, 63·86; phosphorus, 0·033; No. 3, iron, 63·94; phosphorus, 0·059; No. 4, iron, 62·08; phosphorus, 0·040; No. 5, iron, 61·60; phosphorus, 0·075; No. 6, iron, 54·59; phosphorus, 0·082 per cent. The amount of stripping to be done is 2,893,333 cubic yards, and the open-pit, steam-shovel system will be adopted for mining the ore. So far the Biwabik Company has expended over £12,000 without shipping a ton of ore. Attention is called to the fact that there is no hanging wall to this ore-body, and any method of underground mining must take into account the new problems presented in mining a flat deposit of great thickness without a solid roof. But after long deliberation the open-pit system was adopted, and will be prosecuted. The mine is tapped by the Duluth and Iron Range, and the Duluth, Mesabi, and Northern Railways.

Actinolite Magnetite Schists in Minnesota.—Attention has repeatedly been called to the existence of beds of amphibole schists asso-

* *Transactions of the American Institute of Mining Engineers, Montreal Meeting (advance proof).*

ciated with the ores in the older iron ore regions of the Lake Superior district. Consequently, their discovery on the newly opened Mesabi range is of interest from a theoretical standpoint. The descriptions of them given by W. S. Bayley * agree very closely with those given by R. D. Irving and C. R. Van Hise,† for the corresponding schists in the Penokee series, except that in the Minnesota rocks, quartz is rare, and hæmatite is absent. The presence of these peculiar rocks in the Mesabi range is noteworthy, since their origin in other districts has been thought to be closely connected with that of the iron ores with which they are associated.

The Iron Ore Deposits of Missouri.—A. Winslow ‡ corrects a statement made by S. F. Emmons,§ to the effect that the specular ores of South-Eastern Missouri are probably all of Algonkian age. There is, however, a distinction to be made. Those of Iron Mountain occur in Archæan porphyry in tongue-like masses or veins that taper out with depth. The ore of Pilot Knob, on the other hand, occurs as a bed interstratified with clastic Algonkian rock composed of *débris* of the pre-existing Archæan porphyries. At Iron Mountain the ores appear to have been derived from the decay of great thicknesses of porphyry, and to afford examples of chemical concentration from older basic eruptive rocks; whilst at Pilot Knob, the ore-body is probably the result of replacement of certain members of the Algonkian series of strata.

In the iron ore deposits of Central Missouri, which consist of a mixture of blue specular ores and red hæmatite, there are instances of accumulation in cavities and depressions produced by subterranean erosion of limestone. Remote as these ore-bodies are from eruptive rocks, it is necessary to seek for their source in the surrounding sedimentary rocks. The probable contributors are the sandstones, which are often highly ferruginous, and are readily leached by percolating waters. It is probable that the decaying dolomites also contributed a share.

The Franklinite Deposits of New Jersey.—E. F. Dürre|| describes the franklinite deposits of New Jersey, one of the most

* *American Journal of Science*, vol. xlv. pp. 176-180.

† *Journal of the Iron and Steel Institute*, 1892, No. I., p. 274.

‡ *Transactions of the American Institute of Mining Engineers*, vol. xxii. (advance proof).

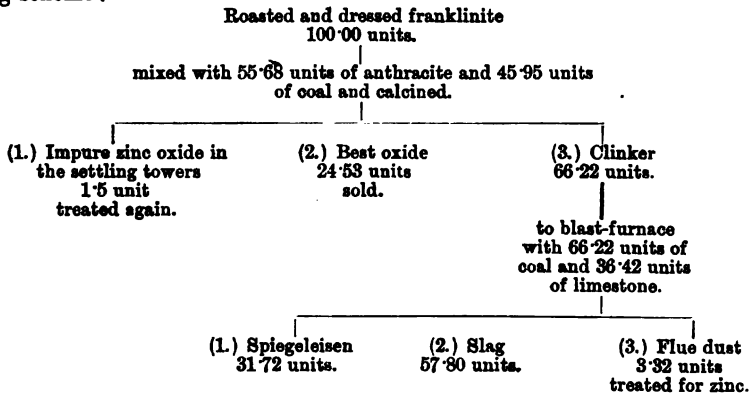
§ *Ibid.*

|| *Zeitschrift des Vereines deutscher Ingenieure*, vol. xxxviii. pp. 184-190.

interesting occurrences of mineral in the United States. As is well known, franklinite is a mineral of the spinel group, and is an ore of iron, zinc, and manganese. It occurs in crystalline limestone, formerly regarded as of Lower Silurian age, but now recognised as of Cambrian age. At Franklin, the crystalline limestone forms a low escarpment at Mine Hill, and appears again near Ogdensburgh at Stirling Hill. The ore-bed crops out at Franklin, and courses 30° west of south as an uninterrupted deposit of some 750 yards in width. Average bulk analyses of the ore gave the following results:—

Description.	Taylor Mine (New Jersey Co.).				Stirling Hill.	
	1.	2.	3.	4.	1.	2.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Silica	10.21	11.06	10.33	11.77	4.86	5.15
Ferrie oxide	31.41	27.54	30.36	30.91	30.33	27.62
Manganous oxide	15.84	17.63	15.96	10.27	12.30	13.09
Zinc oxide	32.83	35.88	26.34	25.71	29.42	23.38
Alumina	0.21	0.24	1.16	2.01	0.67	0.64
Lime	5.09	2.01	7.15	10.43	12.65	14.37
Magnesia . . . . .	...	0.77	1.09	0.99	...	1.98

The author describes and illustrates the furnaces employed for the metallurgical treatment of this ore. The process is shown by the following scheme:—



F. L. Nason* describes the recent explorations made with the diamond drill in the franklinite deposits of Mine Hill, Sussex county, New

* *Transactions of the American Institute of Mining Engineers*, Virginia Beach Meeting, 1894 (advance proof).

Jersey. This deposit has a long continuous outcrop, extending from the extreme southern point 2970 feet N. 16° E., and N. 53° E. for 480 feet. Where the shorter arm disappears, a dyke of mica diabase cuts across both outcrops in an east and west direction. On driving through this dyke, ore was again found on the northern side pitching underground at 27° to 30°, and was worked for 300 feet on the slope. The appearance at the end of the deposit suggested that the two outcrops belong to the same vein, and that they were connected by a synclinal trough. A cross-cut showed also that the eastern edge is folded into a collapsed or compressed anticline. Shallow pits failed to discover the ore, but a number of diamond borings found the ore at varying depths. From the data thus obtained, the author is enabled to illustrate the form of the deposit, which may be regarded as shaped something like a scoop broken away on one side. The ore-body is of large size, and, as known at present, is 3500 feet long, 800 feet wide, and 25 feet thick, as an average over all. The country is white limestone, with intrusive granite in sheets and tongues, but up to the present the granite has not been found in the vein, in which the only intrusive matter is the trap dyke.

The Imataca Iron Ore Range.—S. Norton * directs attention to an important iron ore range, situated fifty-four miles from the mouth of the River Orinoco. This range, he believes, extends for thirty-five miles, and yields ore that could be cheaply worked and cheaply transported. Analyses of the Imataca ore taken from points on the range over a distance of five miles, yielded the following results:—

	Iron.	Phosphorus.	Manganese.	Lime.	Sulphur.	Silicon.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
1 . . .	64·34	0·043	0·089	1·88	0·006	1·55
2 . . .	66·67	0·083	0·069	3·28	0·011	0·70
3 . . .	67·06	0·056	0·085	2·61	0·023	0·53
4 . . .	65·38	0·064	0·231	3·38	0·009	0·86

There appears to be no iron made in Venezuela, and no coal is being worked. All the necessary materials, however, are at hand at Imataca to make charcoal iron.

Iron Ores from the Argentine Republic.—The following

* *Iron Age*, vol. lii. pp. 931-932.

are analyses of iron ores from the Catamarca Province of the Republic: *—

Description.	I.	II.	III.
	Per Cent.	Per Cent.	Per Cent.
Iron	52·64	44·53	...
Ferric oxide . . . . .	...	63·57	52·21
Ferrous oxide . . . . .	...	...	14·89
Manganese oxide . . . . .	...	...	0·97
Alumina	1·80	1·58	5·40
Silica	6·40	23·26	2·55
Oxygen	19·18	...	...
Lime . . . . .	...	0·33	...
Magnesia	2·46	...	...
Moisture	0·72	11·10	0·93
Sulphur	0·10	0·24	...
Titanium anhydride	16·70	...	18·17

The Iron Ores of Northern Africa.—The three most important iron ore deposits on the coast of Northern Africa are at Mokta in the Department of Constantine, at Beni-Saf or Tafna in the Province of Oran, and at Tabarka in Tunis. According to E. Fuchs and L. de Launay, † the Mokta-el-Hadid deposit lies at the foot of the southern slope of a mountain range. It is connected by a railway with the port of Bona. The ore is transported by steamers of 1000 tons capacity to Marseilles.

The Mokta deposit consists of massive specular iron ore, and is considered as replacing a bed of limestone formerly existing between gneiss and mica schist. The ore occurs in lenticular masses between limestones and clays, and by gradual loss of metal passes gradually into pure limestone. In the blast-furnace the ore yields 60 per cent. of iron, and it contains from 0·1 to 0·2 per cent. of manganese. As a general rule, in the deep, magnetite is found, and also in the vicinity of the limestone, when it is of great hardness. The iron glance is evidently connected with surface action, while the magnetite in the neighbourhood of the limestone was probably derived from sulphur compounds by precipitation through the action of the limestone, followed by other metamorphic changes.

The Mokta deposit may be traced for over a mile, and possesses lenticular enlargements and diminutions in size. The first discovered ore mass is now almost worked out. About 500 yards from this a smaller deposit was found, and this has since yielded about 800,000 tons of ore. This, too, is approaching abandonment.

* *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlii. p. 21.

† *Traité des Gîtes Minéraux et Métallifères*, Paris, 1893, vol. i. pp. 721-728.

Two kinds of ore are distinguished, both consisting of mixtures of sesquioxide and magnetite. These are the "red" and the "grey," and neither contains either sulphur or phosphorus. An analysis showed—

Fe_2O_3 .	Mn_2O_4 .	SiO_2 .	Al_2O_3 .	CaO .
88.25	2.50	6.10	1.50	0.45

For a long time this deposit was worked open-cast, but now deep mining is almost solely employed; the ton of ore costing about eighteenpence to mine, apart from transport, &c., charges. The ore in this Mokta deposit has been estimated at about 12 to 15 million tons, one half of which has been worked out. About 500 or 600 men are employed at the mines in summer, and from 800 to 900 in winter.

The Tafna or Beni-Saf mine is situated at the mouth of the Tafna river. The ore appears to be a bed, and is of Tertiary age. It consists of a series of enormous lenticular masses, in probably Liassic slates. These slates are grey or pink in colour, very much metamorphosed and talcose in character. When in contact with the ore they appear converted into white kaolin. These slates are surrounded by chalk and Miocene deposits. The ore is a dark red or blackish blue hæmatite. It is nearly always very readily decomposed, falling into powder. This renders the ore unsuited to the requirements of the French blast-furnace companies, which only work on lump ore. It yields in the furnace about 67 per cent. of metal, and contains from 2 to 3 per cent. of manganese, with no silicon, sulphur, or phosphorus. The remainder is calcium carbonate. The ore masses are much larger than those at Mokta, and in one case the ore-body, consisting of nearly pure ore, is 100 yards thick and 400 or 500 in length. Commencing at the eastern end of the deposit, a heterogeneous mixture of ore and limestone is met with, though foot and hanging walls are always observed. The annual output is about 350,000 tons, this output being ensured for another fourteen years. The total number of workmen employed is about 1000, 300 of whom are actual miners. Each miner is supposed to raise 6 tons of material a day.

The Tabarka deposits exist mainly in tertiary formations, the lower Eocene and the Miocene. The ore lies upon marl or tertiary marl clays. The ores found are mainly either red or brown hæmatites, somewhat high in manganese, together with some micaceous iron glance. The Maknas portion of this deposit contains richer ore. Ore from the Neftas district contains ore with from 74 to 79 per cent. of ferric oxide, 2.3 to 9.4 per cent. of the red oxide of manganese, and 0.04 to 0.07 per cent. of phosphoric anhydride. Iron glance is of frequent occurrence on the right bank of the Oued bon Zenna, and contains from 60 to 62 per cent.

of iron. The ore is thought to be of aqueous origin. Nearly everywhere it is found that the ore or mineralised conglomerate rests on a bed of white or bluish clay. About 5,000,000 tons of ore exists in the three concessions of Nefzas and Moghadi, and a line of railway and a port are proposed to open up these deposits.

The Iron Ores of Persia.—A. F. Stahl* observes that as yet but little iron or steel is used in Persia. Russian imports through the ports of the Caspian Sea amount to about 2000 tons a year, and a still smaller quantity is imported from India, and through the ports of the Persian Gulf. The price at which iron is sold in Persia is very high, owing to the difficulties of transport. The actual production of iron in Persia is very small, a little being produced from the brown iron ores found at Amol. Among the more important of the known deposits of iron ore are two magnetite lodes near Kaschan, micaceous iron ore near Nain, and specular ore and magnetite to the east of Yeza, and about six miles to the north-east of Bafk. This is the most important iron ore deposit in Persia. It occurs in the form of an isolated hill in the midst of a desert. This hill the author estimates to contain nearly 8,000,000 cubic yards of ore, and some hundreds of thousands of tons of ore exist as drift within a mile or so of the hill. Less than 20 miles from this deposit, near Narigan, is a lode of brown and red iron ores some 25 or 30 yards in width, and important deposits of these ores also occur at Bashkan, in the Baabad district.

All these deposits of ore occur at considerable distances from the known deposits of coal, but a deposit of red hæmatite containing about 70 per cent. of ferric oxide, which is found near Ardake, 43 miles to the west of Teheran, is in the immediate neighbourhood of large deposits of coal. The author considers that this would be the most favourable spot in Persia at the present time for the erection of a blast-furnace plant. Other deposits of iron ore occur a few miles to the east of Teheran; to the north and east of Semnan; between Damghan and Schahrud; near Agere; in the Tue-Dervar Pass, and between Tasch and Tscheharbag. Most of these occur at no very great distances from deposits of coal.

Iron Ore in Corea.—Some particulars regarding iron ore in Corea have been gathered by Mr. Heard, the United States Consul at Séoul. No statistics are available, but all the iron employed in the country is of native origin, and the ore is found in great abundance in several parts of the country. The ore is apparently of good quality. At present all

* *Chemiker Zeitung*, vol. xvii. p. 1910.

the mines are worked by natives, who, however, do their work in the most rudimentary manner, no ventilation, lighting, or draining being employed. Much of the ore is magnetic, and is smelted in a form of the Catalan forge. No coal has at present been discovered in the country.

The Origin of Iron Ore.—In discussing a paper by W. P. Jenney on the lead and zinc deposits of the Mississippi Valley, F. L. Nason * refers to the iron ore deposits as throwing some light on the two theories of their origin proposed by Jenney and by Whitney and Chamberlin. The larger deposits of specular ores of the sandstone region occupying the plateau of the Ozark uplift have been formed in caves, although smaller lenticular masses have simply replaced the limestone. The Cherry Valley deposit as now known is about 400 feet long by 300 feet wide, and 100 feet in depth. The side walls have been exposed, but the ore has deteriorated at the north end and in the floor, although it is good at the south breast. The arrangement of the neighbouring rocks shows that this deposit lies in a limestone ravine formed by the falling away of the sandstone over the caves, which conveyed an underground spring to the valley below. All ore deposits are similarly found near to large drainage ravines. Limonites are also found in this district, but are characteristically further down the slopes of the uplifts than the specular ore. They may be divided into four classes:—specular ore altered *in situ*; specular ore dissolved and redeposited at a lower level; limonite deposits from the leaching of the rocks; and deposits derived from the original deposits of iron sulphide. A deposit typical of the latter class is described as occurring near Thomasville, Oregon county. None of these deposits can be considered as owing their origin to chalybeate waters coming from below. In reply, W. P. Jenney points out that stalactitic formations do not necessarily imply deposition of ores by descension, as stalactites may be formed subsequently to deposition.

French Manganese Ore.—The carbonate of manganese found at Les Cabesses in the Ariège Department, France, is of considerable purity. Samples of it contained :†—

	Raw Ore. Per Cent.	Calcined Ore. Per Cent.
Manganese	45·680	56·480
Silica	5·940	6·480
Phosphorus	0·043	0·047

* *Transactions of the American Institute of Mining Engineers*, Chicago Meeting, 1893 (advance proof of discussion).

† *Stahl und Eisen*, vol. xiv. p. 20.

Native Iron from the Lizard.—In the veins traversing the gabbro and serpentine of the Lizard district, T. Clark * has discovered native iron as disseminated grains.

Magnetite from Madras.—T. H. Holland † describes a specimen of magnetite containing manganese and alumina from the Kodur mines, Vizagapatam district, Madras Presidency. Analysis gave the following results :—

H ₂ O.	FeO.	MnO.	Al ₂ O ₃ .	Fe ₂ O ₄ .	Mn ₂ O ₄ .	Total.
2.19	27.03	0.94	2.54	65.22	2.08	100.00

On comparing the analytical results with previously recorded analyses of magnetites, it is seen that manganese has been found replacing the iron, either with or without magnesia, but the author knows of no case in which at the same time alumina replaces the sesquioxide. The Vizagapatam specimen is thus a new variety.

Recent Researches on Meteorites.—O. W. Huntington ‡ discusses the observations hitherto made upon the occurrence of diamonds in meteorites. In order to demonstrate that true diamonds occurred in this way, he dissolved many pounds of the Cañon Diablo iron in order to obtain enough diamond dust to use for cutting rough diamonds. About 200 lbs. of the iron was examined, and the most promising pieces were dissolved by being successively suspended by a platinum wire in a platinum bowl, filled with hydrochloric acid nearly saturated with chloride of iron and then slightly diluted with water. The iron was made the positive pole of a battery consisting of 12 gravity cells, the bowl forming the other electrode. When the conductivity of the solution was properly adjusted by means of the chloride of iron, it was found that only the pure iron of the meteorite would dissolve, thus setting free the plates of schreibersite and tænite as well as the graphite and other impurities, and bringing out the crystalline structure of the meteorite in wonderful perfection.

The iron was dissolved in two- or three-ounce pieces, and it at once appeared that there was a wide variation in its composition. Most of it contained no diamonds whatever. One piece, however, in the process of dissolving showed an irregular vein running through it, consisting of

* *Journal of the Royal Institution of Cornwall*, vol. x. p. 396; *Zeitschrift für Kristallographie und Mineralogie*, vol. xxii. p. 303.

† *Records of the Geological Survey of India*, vol. xxvi. pp. 164, 165.

‡ *Proceedings of the American Academy of Arts and Science*, vol. xxix. pp. 204-211, with five illustrations.

a white vitreous substance varying in width from a fine line to nearly four millimetres. On trying the hardness of the vein-stuff, it was found to exceed that of the ruby. On further examination it appeared to be a mixture of iron, a sulphide of iron, silica, amorphous carbon, and diamond, so that it finally had to be crushed in order to get rid of all the iron. The hardest grains were isolated, and when examined under the microscope one minute but perfect octahedron of diamond was found, transparent and colourless. It was separately mounted on a microscopic slide but soon disappeared, and in its place were found only some very minute angular fragments. A second crystal was afterwards isolated, but disappeared in a like manner, suggesting that these crystals had been formed under pressure, and when exposed in a warm room had exploded.

About half a carat of diamond powder was finally obtained, being separated by its specific gravity from a very large quantity of amorphous carbon. The particles varied from colourless through yellow and blue to black. Many of them appeared to be angular fragments, though some of them looked not unlike hyalite, except for their more brilliant lustre. Several perfect little octahedra were found that did not break up.

A portion of the powder was successfully used for the diamond-cutting experiment. Thus the combined evidence of the author's work, with that of C. Friedel * and Moissan establishes the fact that the Cañon Diablo iron contains true diamonds, and not any new allotropic form of carbon.

L. G. Eakins † describes a new meteorite from Hamblen county, Texas. It was found in September 1887, on a ridge six miles from Morristown, Tennessee. The various pieces found weigh about 36 lbs. Most of the pieces show much surface oxidation, a fresh fracture showing a grey colour, with numerous metallic particles of nickel-iron. The latter gave on analysis the following results :—

Fe.	Ni.	Co.	Cu.	P.	S.	Total
90·92	7·71	0·80	trace	0·19	0·04	99·66

The siliceous portion of the meteorite gave the following results :—

	SiO ₂ .	Al ₂ O ₃ .	Cr ₂ O ₃ .	FeO.	NiO.	MnO.	CaO.	MgO.	K ₂ O.	Na ₂ O.	P ₂ O ₅ .	S.	Totals.
I.	16·79	8·33	...	4·88	0·39	...	5·19	1·34	...	...	0·46	0·25	37·63
II.	31·47	9·25	0·82	6·55	...	0·47	2·24	11·16	0·02	0·12	...	...	62·10

* *Journal of the Iron and Steel Institute*, 1893, No. I. p. 196.

† *American Journal of Science*, vol. xlv. pp. 283-285.

I., Portion soluble in hydrochloric acid; II., insoluble portion. In many stony meteorites, olivine forms the bulk of the soluble portion. In this case, analysis shows olivine to be present in but small proportion, if at all.

An analysis of a meteorite found in the Moonbi Range, in Australia, has been made by J. C. H. Mingaye.* The mass weighed 29 lbs. and had a specific gravity of 7.681. Its composition, which is somewhat similar to that of the Bingera meteorite from New South Wales, is as follows:—

Fe.	Ni.	Co.	Cu.	Sn.	Cr.	C.	Si.	P.	O.
91.350	7.886	0.564	trace	0.003	trace	0.068	0.039	0.217	trace

The occluded gases were hydrogen and nitrogen.

S. Meunier† has examined specimens of the meteorites recently presented to the Museum of Natural History by Halid Edhem Bey. The first was found in 1873 at Tirnowa in Roumelia. It is covered with a black crust about a millimetre in thickness. On fracture, a clear grey mass is presented, characterised by its clastic or fragmentary structure. Its specific gravity is 3.69. The meteorite belongs to the lithological type designated since 1870 in the Museum collection by the name of *mesminite*.

The second meteorite fell on June 2, 1883, in a forest near the village of Urba. It is uniformly white. It has a specific gravity of 3.427, and is very finely granular.

II.—IRON ORE MINING.

Ancient Iron Ore Mining.—L. Meachem ‡ describes the traces of ancient mining that have been found at the Coppice, Sedgley. At this place the thick coal lies at 1 in 27, and the surface did not appear to have been disturbed. On opening up the ground it was found, however, that the iron ore underlying the coal had been extracted by means of bell pits which were about 5 feet in diameter at the top, 12 feet at the bottom, and 15 to 20 feet deep. These pits had been filled up with the broken coal and rubbish. Near these pits the traces of a furnace were found. Apparently charcoal had been used as fuel, as the coal did not

* *Engineering and Mining Journal*, vol. lvi. p. 501.

† *Comptes Rendus de l'Académie des Sciences*, vol. cxvii. pp. 257-258.

‡ *Transactions of the Federated Institution of Mining Engineers*, vol. vi. pp. 554-557, with one plate.

seem to have been utilised. No tools of any kind nor traces of timbering were discovered, and the date was quite uncertain, but it might be referred to Roman or to prehistoric times.

Exploration for Magnetic Iron Ore.—E. A. Sjöstedt * describes Tiberg's magnetic inclination scale for magnetic explorations. Until recently, only the miner's compass and Thalén's magnetometer have been used for this purpose.† The instruments constructed by E. Tiberg afford a simplified and trustworthy method. They consist of a so-called magnetic inclination scale, a plane-table, and an alidade instrument. These instruments and the method of conducting the survey above and below ground are fully described, and formulæ are given for calculating the vertical intensity, the horizontal intensity, and the vertical distance from the surface to the upper pole of a vertical ore deposit.

III.—MECHANICAL PREPARATION.

The Dressing of Spathic Ores.—G. Gromier ‡ describes the preparation of spathic ore at Allevard. The gangue consists of schist, sand, and quartz, the latter being closely intermingled with the ore. After a rough hand-picking by the miner, the ore is separated by shaking screens into two sizes which are treated as follows :—

Above 30 mm. (1·18 inch).
Hand-sorting.
Calcining in kilns.
Hand-sorting after calcining.
Magnetic separation.

Below 30 mm. (1·18 inch).
Mechanical sizing.
Washing.
Calcining in reverberatory furnaces.
Agglomeration.

Large ore as it comes from the screen is washed by jets of water, and then falls on to an endless belt made of old aloë ropes, where it is hand-picked. It is then taken to the kilns, where carbonic anhydride to the amount of 30 per cent. of the weight is removed. The kilns are heated by gas. They are divided by a constriction about the centre of the height, the part above being cylindro-conical and forming the combustion chamber, the part below forming the cooling chamber. Gas for each kiln is supplied by a set of three producers. Each furnace yields about

* *Transactions of the Mining Society of Nova Scotia*, vol. ii. pp. 117-129.

† These instruments were described in a paper communicated by B. H. Brough to the Iron and Steel Institute (*Journal*, 1887, No. I. p. 289).

‡ *Bulletin de la Société de l'Industrie Minière*, vol. vii. pp. 465-485, with six plates.

25 tons of calcined ore per 24 hours, with a consumption of 66 lbs. of coal per ton. The temperature is about 1000° C. After calcination, the ore is lifted by an elevator to fixed screens with 30 mm. (1.18 inch) holes. A second hand-sorting is then performed on tilting-tables, and the part removed is treated in magnetic separators after passing through ore breakers. The ore thus treated contains 50 per cent. of iron and manganese. By far the larger part of the ore is under 30 mm. (1.18 inch) in size. It is separated by a series of three trommels into the following sizes :—

Millimetres	0-2	2-3	3-5	5-9	9-15	15-30
Inches	0-0.08	0.08-0.12	0.12-0.2	0.2-0.35	0.35-0.59	0.59-1.18

The ore up to 2 mm. (0.08 inch) in size is treated in Hartz jigs, on a bed of ore from 9 to 15 mm. (0.35 to 0.59 inch) in size. The sizes between 2 and 15 mm. (0.08 and 0.59 inch) are carried by water to continuous jigs. The washed ore is then calcined in gas-fired reverberatory furnaces, arranged so that the ore before leaving heats the incoming air. The hearths of the furnaces are inclined or stepped. The calcined ore is wetted in order to slake the caustic lime and magnesia, and is then lifted by an elevator to a Couffinhal press, where it is subjected to a compression of 8533 lbs. persquare inch, into bricks about $5\frac{1}{2}$ by $5\frac{1}{2}$ by $4\frac{1}{2}$ inches, and weighing about 15 lbs. The bricks are dried for about 8 days, and will then bear a weight of 210 lbs. per square inch. Motive power is supplied by Girard turbines, 12 horse-power being used for the first screens and picking belts, 8 for the magnetic separation, 45 for the treatment of the fine ore, and 40 for the agglomeration plant. Details of the outturn and labour are given, with dimensions of the jigs, and the various machines are fully illustrated.

Washing Iron Ore in Virginia.—G. R. Johnson * describes the plant for washing iron ore at Longdale, Virginia. Before 1883, the ore was worked open-cast, but after that date the ore was obtained by underground mining, and then had to be washed. Log-washers of the ordinary type were used, and were replaced in 1891 by a new plant of the same type of washer. This consists of two pairs of washers driven by belt and spur gearing from a 25 horse-power engine. The logs are driven at twelve revolutions per minute, and have an inclination of $\frac{3}{4}$ inch per foot. They are made of cast iron flanged pipe $\frac{3}{4}$ inch thick, $11\frac{1}{2}$ inches in diameter, and $17\frac{1}{2}$ feet long. The spoons are put

* *Transactions of the American Institute of Mining Engineers*, Virginia Beach Meeting, 1894 (advance proof).

on in two spiral threads of five feet pitch, the opposite spoons being held on the log by two through bolts with nuts at each end. The upper gudgeon carries the revolving screen. The troughs are lined with semi-circular iron castings 15 inches long. Ore is brought over the feeding shoots in side-tipping trucks holding $5\frac{1}{2}$ tons, and is fed up the troughs into the revolving screens. The fine ore that passes through the $\frac{3}{16}$ -inch holes in this screen falls on to fixed inclined screens of 14-mesh wire cloth, where it is further washed and screened. That part which passes through these screens is at present carried away with the muddy water, but it is probable that this will be saved in the future. Screens are also placed to catch ore which is carried away by the water over the lower end of the troughs. Two of these screens are used, one only being worked at a time whilst the other is being discharged. The average of six days' work in March last showed:—

Coal burnt per day, lbs.	1479·16
Unwashed ore, tons	196·2
Washed ore, tons	138·9
Ore saved, per cent.	70·8
Hours run	5·37½
Men employed	6

Magnetic Separation.—In discussing W. P. Blake's* paper on the separation of blende from pyrites, C. Q. Payne† confirms the author's view that it is possible to separate calamine after roasting. Ore worked at Austinville, Virginia, consists of galena, calamine, and limonite. It is crushed, washed free from clay in log-washers, and jigged to separate the galena. The zinc and iron ores are then roasted in reverberatory furnaces, three to four hundred pounds of fine coal-dust per ton of ore being added near the end of the operation in order to render the iron oxide magnetic. After drawing the ore from the furnace, it is partly quenched with water and passed through the separator. During the first nine months, 1415 tons of crude material yielded 675 tons of iron ore, with 50 to 55 per cent. of metallic iron. The tailings, which contained the zinc, carried from 4 to 6 per cent. of iron.

IV.—METALLURGICAL PREPARATION.

Kiln for Iron Ores.—An illustration has recently been given of the latest form of the Davis-Colby calciner,‡ which has been success-

* *Journal of the Iron and Steel Institute*, 1893, No. II. p. 331.

† *Transactions of the American Institute of Mining Engineers* (advance proof).

‡ *Engineering and Mining Journal*, vol. lvi. pp. 665-666.

fully used in Pennsylvania for treating iron ores. The ore is treated in an annular chamber surrounding a central flue, and in turn enclosed by an annular gas-combustion chamber, the products of combustion passing through the ore from the outer chamber to the central flue. The series of arches used in the earlier forms are now omitted in the combustion chamber. The ore is fed over a central cone, and is drawn through doors at the base placed at such a height that the roasted material falls directly into the waggons. These kilns are not only used for sulphurous ores, but also for carbonate and brown ores. One kiln at Shelby, in Alabama, is 30 feet in height, 17 and 14 feet in diameter at the bottom and top respectively. It is supplied by a single Taylor gas-producer, using $2\frac{1}{2}$ to 3 tons of bituminous coal in twenty-four hours for roasting 125 tons of ore. The waste gases from the blast-furnace may be used.

The Metallurgical Treatment of Nickel Ores.—Modifications of the method of treating nickel ores described by R. H. Ahn * as being in use at Sudbury, Ontario, are as follows :—The pyrrhotite, containing 2·7 per cent. of nickel, is heap roasted, smelted in a cupola for regulus with the richer slags; Bessemerised, the concentrated Bessemer regulus calcined with salt and steam; lixiviated, and the solution treated by the ordinary wet methods for nickel and copper; the residue, consisting mainly of the oxides of iron and nickel, run down with sand, sodium sulphide, and charcoal; the regulus heated with nitre, and the oxide run down with soda ash, sand, and charcoal, the resulting nickel being granulated in a stream of water.

The second method consists in smelting down the coarse regulus produced as above with sodium sulphate, and coke. A double layer of regulus results, the upper one chiefly of copper and iron, the lower one mainly of nickel. The upper layer is allowed to weather, and is then added to the charge for coarse metal. The lower layer of regulus is fused with sodium sulphate and coke. The nickel collects in a concentrated regulus, which is calcined and run down with sand. A still more concentrated regulus is produced, which is heated with nitre. Oxides of nickel form, which are partly sold as such to ironworks, and partly reduced to the metallic state. This metal contains carbon, silicon, and iron, from which it is freed by oxidation in an acid-lined reverberatory furnace. Further details relating to the treatment of nickel ores have also been published by J. H. L. Vogt.†

* *Stahl und Eisen*, vol. xiv. p. 19.

† Den canadiske nikkelindustri; bessemering af nikkelsten; udsigterne for den norske nikkelindustri. Christiania; *Stahl und Eisen*, vol. xiv. pp. 23-26.

REFRACTORY MATERIALS.

Basic Bricks.—The basic bricks used in lining converters at the Pottstown Steelworks are stated by H. Wedding * to have the following percentage composition :—

CaO.	MgO.	Al ₂ O ₃ +Fe ₂ O ₃ .	SiO ₂ .	P.
91·52	1·16	5·96	1·14	0·22

The Calculation of the Fusibility of Clays.—H. A. Wheeler † has examined 110 samples of Missouri clays, and finds that Bischof's formula for expressing the fusibility is untrustworthy. Very satisfactory comparative values are given by the following formula :—

$$\text{Fusibility factor} = \frac{N}{D + D'} \quad (\text{A})$$

in which N represents the sum of non-detrimental constituents, or total silica, alumina, titanin anhydride, water, moisture, and carbonic anhydride; D represents the sum of the detrimental constituents, ferric oxide, lime, magnesia, alkalies, sulphuric acid, &c., and D' the sum of the alkalies which have been found to have about double the fluxing value of the other fluxes. Still better results are obtained with the formula :—

$$\text{Fusibility factor} = \frac{N}{D + D' + C} \quad (\text{B})$$

in which N, D, and D' have the same values as in formula A, and C is a constant that has different values according to the density and fineness of the clay. When the clay is coarse-grained and exceeds 2·25 in specific gravity, the constant may be taken as 1; whilst, when the clay is fine-grained and has a specific gravity of 1·75 to 2·00, its value is 4. A large amount of work has still to be done in order to arrive at trustworthy values for C.

The following are some of the author's results showing the value of calculated fusibilities :—

* *Stahl und Eisen*, vol. xiii. p. 1029.

† *Engineering and Mining Journal*, vol. lvii. pp. 224-225.

	I.	II.	III.	IV.
SiO ₂	64.35	61.73	46.18	45.12
Al ₂ O ₃	21.16	23.56	38.12	40.46
H ₂ O	8.54	9.25	14.01	13.34
Total N	94.45	94.54	98.31	98.92
Alkalies D'	0.51	1.00	1.20	0.30
Total D	4.81	7.30	2.06	1.06
Specific gravity	2.13	2.47	2.42	2.33
Grain	fine	coarse	fine	very fine
Fusibility (degrees Fahr.)				
Incipient	2200	2100	2300	2350
Complete	2400	2300	2500	2550
Scoriaceous	2700	2500	2700	2700
Calculated values—				
Bischof	1.44	1.23	16.0	37.0
Wheeler's A.	17.7	11.4	28.0	73.0
Wheeler's B.	13.0	10.2	18.0	29.0

I. Christy fireclay, washed; II. Mine run; III. Non-plastic fireclay, Pendleton; IV. High Hill.

The Le Chatelier pyrometer was used in observing the temperature.

The results of some experiments for determining the refractoriness of fireclays are given by H. O. Hofman and C. D. Demond,* together with an account of the general question. There are two methods of determining this factor, the theoretical and the practical. The formulæ of Bischof and of Seger for the deduction of the refractory character from the chemical analysis are shortly discussed; and it is pointed out that, as clay is often a mixture and not a pure chemical compound, the mechanical state has considerable influence, and therefore that practical determinations are preferable. The latter methods may be carried out directly or indirectly. By the direct method, a sample of clay is subjected to high temperatures, and its fusibility is noted. By the indirect method, fluxes or refractory materials as required, are added to the clay, until the mixture shows the same behaviour as a standard clay. Examples of both methods are given, and it is shown that the difficulty of exactly controlling the temperature is a serious drawback to the reliability of these methods. The authors have therefore devised a furnace in which the operations can be watched, and a method in which a temperature approximating to the melting-point of platinum, or 1775° C., is used. The furnace is a small one of the reverberatory type, gas fired and carefully protected with non-conducting material. At the foot of the chimney is a working door, through which samples are introduced by platinum tongs. Both the

* *Transactions of the American Institute of Mining Engineers*, Virginia Beach meeting, 1894 (advance proof).

air and gas are heated prior to admission, by passing them through two coils of iron pipe, which are heated by solid fuel. Le Chatelier's pyrometer was used to determine the area of the hearth over which the heat was approximately uniform, and finally this instrument was also used as the standard for temperature measurements, as Seger's cones did not appear to exactly meet all requirements. The form adapted for the test is a triangular cone measuring $\frac{3}{4}$ by $\frac{3}{4}$ by $\frac{7}{8}$ inch, and $2\frac{5}{8}$ inches for the sides, the dried material being mixed with the flux and with dextrin solution if necessary. The clay is finer than that required to pass a 100-mesh sieve. The flux used is a mixture of calcium carbonate and silica, in the ratio of one to three, or preferably of one to five. A large number of tests have been made, and illustrations are given of the cones after treatment. The results are tabulated, showing the chemical composition of the mixture and also its components of clay, quartz, and calcium carbonate, the refractory quotient as calculated by Bischof's and by Seger's methods, the temperature attained, and the effect on the cone.

FUEL.

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I.—CALORIFIC VALUE.

Recent Advances in Pyrometry.—In a comprehensive paper on the recent advances in pyrometry, Professor W. C. Roberts-Austen * deals generally with the history of heat measurement, and describes more fully all the later forms of apparatus used for the determination of high temperatures. References to the original sources, in which descriptions of the apparatus and of the results of experiments will be found, are freely given. Amongst the instruments described more or less fully are the Siemens electrical resistance pyrometer and Callender's modification of it, also Le Chatelier's thermo-couple and the various autographic apparatus used with it by the author and others. The great advantages arising from the use of these latter forms for experimental work, and for practical work in connection with the blast-furnace, are entered into at some length. At least four other methods have taken a place in industrial practice, and these are calorimetric and optical methods, pyrometric alloys, and Barus' method, depending on the viscosity of gases. Calorimetric methods and pyrometric alloys both give good results, if used with care. Of optical instruments, the latest forms are Le Chatelier's photometric appliance and Nouel and Mesuré's polariscope. The former compares the luminosity of a standard lamp with the source of heat to be measured; the latter contains a quartz plate and two Nicol prisms, one of which is turned over a graduated

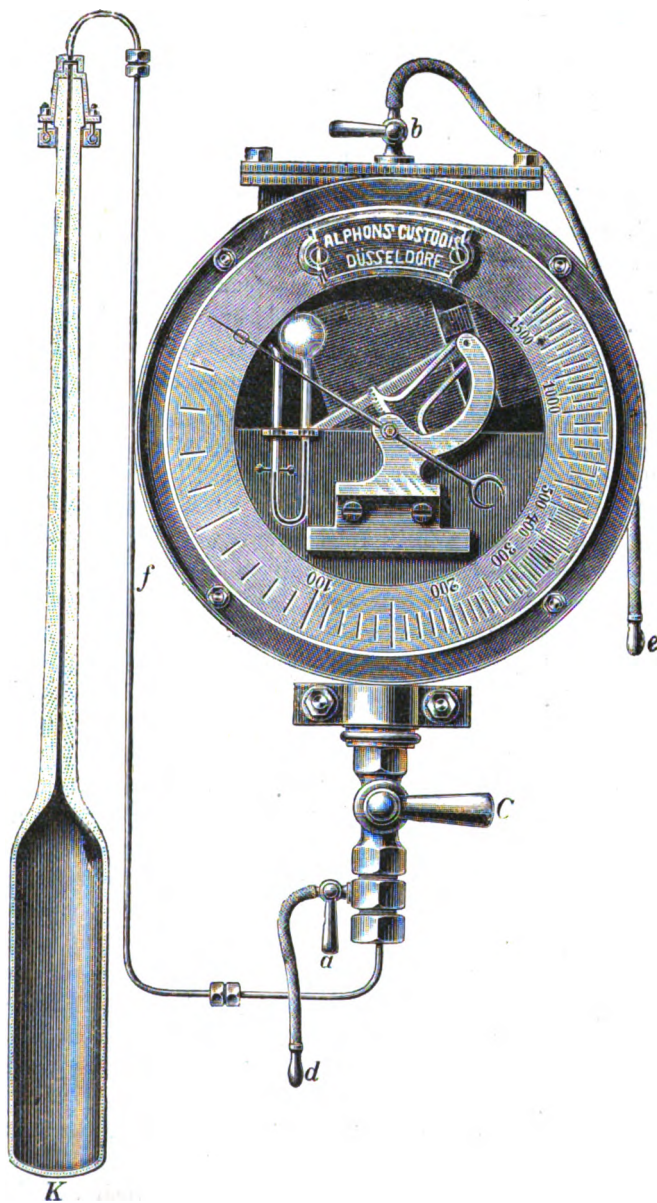
* *Transactions of the American Institute of Mining Engineers*, Chicago meeting, 1893 (advance proof).

scale, to produce maximum extinction of light. The results obtained with these apparatus are given. The method devised by Barus depends on the rate of flow of gas through a capillary tube or fine orifice, this varying inversely as the absolute temperature and viscosity. Pyrometers are graduated by a number of fixed points, varying up to the melting-point of platinum at 1775°C. , which have been determined by the air-pyrometer and by calorimetric methods. The question of the agreement between various pyrometers has been dealt with by several experimenters, including Barus, who has compared the thermo-couple with the air-pyrometer, with the result that for practical work the former may be used to replace the latter. Modified forms of the cumbersome air-pyrometer have, however, been devised for use in works.

The Dürr and Siegert Pyrometer.—According to C. Gaab,* the air-pyrometer patented by Walter Dürr and A. Siegert compares in accuracy with the well-known Le Chatelier, Siemens, and Braun and Wiborg pyrometers, and possesses in a marked degree the characteristics requisite for so important an instrument as the pyrometer. These characteristics that a trustworthy pyrometer should exhibit are solidity of construction, applicability to all classes of work, constant indication of temperature so that all variations in heat may be followed, trustworthiness of the indications, absence of elaborate manipulation on reading, and, lastly, the possibility of being able to ascertain the temperature at some distance from the point of observation. The accompanying illustration shows that this pyrometer fulfils all these requirements.

In a cast-iron case about 200 millimetres (7·87 inches) in diameter, and 125 millimetres (4·91 inches) in height, there is a bell, open below. This is capable of swinging round a knife edge, and is counterbalanced by a counterpoise. At the base of the cast-iron case there is a support with a cock screwed in, and also with a narrow gas-pipe screwed in from the inside, passing fairly high into the interior of the bell. When the instrument is required for use, pure paraffin oil of the best quality is poured into the cast-iron case up to the height of a screwed-in overflow pipe. In this way the air in the bell is prevented from escaping from below, and is able to communicate with the outer air, or with that enclosed in some other space, only through the narrow gas-pipe and cock. The air referred to is contained in a porcelain cylinder, K, which is hermetically connected with the cast-iron case, the so-called indicating apparatus, by means of a copper tube 1 millimetre in internal diameter.

* Abstract of a paper communicated to the Iron and Steel Institute, May 1894.



If this cylinder K is inserted in a space whose temperature it is required to determine, on account of the increase in temperature of the cylinder K, the air in it will expand, and a part of the air proportioned to the heating will be forced out from the cylinder K through the copper pipe *f*, and will pass into the bell. In consequence of this amount of air entering, the bell will be raised, and will by means of a rack and pinion actuate a pointer, which indicates on a scale the temperature of the space in which the cylinder K is placed, in a similar manner to that in which a manometer shows pressure of steam.

It is evident that the scale may be accurately graduated without difficulty. The volume of the cylinder is known, and it is therefore easy to calculate how many cubic centimetres of air are forced out by a heating of x degrees. Moreover, the volume of the bell is known, so that it is easy to determine the height this is raised when the number of cubic centimetres of air, corresponding with a heating of x degrees, pass into the bell. In this way sufficient data are obtained to graduate the scale.

The length of the copper tube may be as much as 33 yards without appreciable differences arising. It is, however, always advisable not to make the tube unnecessarily long, if only on account of its high price. Numerous practical experiments have shown that this pyrometer is a thoroughly useful and trustworthy instrument.

The construction of the indicating apparatus and of the copper tube is thoroughly solid. There is no part liable to rapid depreciation or injury. Even the apparently fragile porcelain cylinder lasts for a very long time, especially when it is allowed to remain in one place, as in blast pipes, reverberatory furnaces, or steam boilers. In order to protect it from external influences, it is enveloped in asbestos and placed in a tube. Internal pressure is never caused by the heating, as this pyrometer works with rarefied air, and the porcelain cylinder only receives internally the ordinary atmospheric pressure at the maximum temperature of the pyrometer. The rarefaction of the air is effected when the instrument is first brought into action by simply exhausting the air from the apparatus to a certain degree. The cylinder is then placed in the place whose temperature is to be ascertained, and the instrument will work continuously without any manipulation being necessary for reading off the temperature.

While the cylinder is in position, an indicating apparatus is fixed at some other point, in some cases as much as thirty yards away, in an office or other suitable place where the temperatures and their variations are always evident.

The Calorific Power of Fuel.—H. von Jüptner* observes that any rapid method for this determination which is based on making, in the first instance, a complete analysis of the fuel is not a practicable one, and it is difficult, in this case, to obtain a sample which shall represent accurately the average composition. The combustion, too, of large quantities, as has been suggested, is not a method which could always be applicable in ordinary work. The old Berthier method, in its simple or derived form, is just the sort of method which is required for ordinary work, but unfortunately the results are not accurate. Another simple method is that of Gmelin, who determines the moisture and the ash in a coal, and then calculates its calorific value by the formula, $p = [100 - (\text{water} + \text{ash})] 80 - 6c$ water, in which the coefficient c is dependent on the percentage of moisture present, and has the following values :—

Percentage of Hygroscopic Water.	Value of C.
Less than 3	- 4
3 to 4.5	+ 6
4.5 to 8	12
8.5 to 12	10
12 to 20	8
20 to 28	6
Over 28	4

This method is based on the accuracy of the supposition that the hygroscopic character of a fuel must be dependent on its composition, but unfortunately the difficulties connected with the determination of the hygroscopic moisture in a so-termed "air dry" fuel are great, owing to the variations in the value of the expression with the temperature, barometric pressure, degree of humidity of the air, &c. These variations account for the fact that, although the values based on the Gmelin formula are, as a rule, of practical value, and much more accurate than those based on the Dulong formula, they still sometimes differ from the true values to a not inconsiderable degree. The author has therefore endeavoured to devise a method which, while equally simple, is yet more accurate, and is not so dependent on local circumstances, and he has adopted one which is based on the action of the coal when subjected to distillation, and on the quantity of oxygen required for its complete combustion. It is as follows :—One gramme of the coal is dried at 100° C. and the moisture determined. It is then heated in a covered platinum crucible in the manner usual in the determination

* *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xli. pp. 420-422, with illustrations.

of the coke, until gas ceases to be evolved. The loss of weight represents the gas yield (G). The residue of the weight P is now burnt, when the percentage of ash, A, and that of the fixed carbon, K, are obtained. The percentage of oxygen required for the complete combustion may be ascertained by the Berthier method. The calorific power of the coal is composed of that of the fixed carbon and that of the combustible gases. The former is readily obtained by simply multiplying the percentage of coke, K, by its mean calorific power, 7630 calories; P then equals $76.30 K$. The calorific value of the volatile gaseous products can only be ascertained from the percentage of oxygen required for their complete combustion. As 12 kilogrammes of carbon require 32 of oxygen for their complete combustion to carbonic anhydride, one part by weight of carbon is equivalent to $\frac{32}{12}$ or $\frac{8}{3}$ parts by weight of oxygen. The oxygen required for the carbon existing as coke is consequently $S_1 = \frac{8}{3} K$, and therefore for the complete combustion of

the gaseous products the oxygen required is $S_{11} = S - S_1 = S - \frac{8}{3} K$.

The composition of the volatile products varies, however, very greatly, even though the temperature at which the distillation is effected is assumed to be a constant one. It depends on the nature of the fuel distilled. The difference is not only marked by the ratio $\frac{G}{K}$ borne by the gas yield of the coal to that of the coke, but still more so by the ratio borne by the oxygen required by the volatile products to that required by the coke $\frac{S''}{S'}$, and this ratio the author has chosen for the empiric determination of the calorific value of the gaseous volatile products. It may be expressed as the product of the oxygen required by the volatile products, $\frac{S}{100}$, yielded by 1 kilogramme of fuel, and the calorific power C as that of these volatile products in relation to 1 kilogramme of oxygen. This coefficient had to be calculated, and the author gives tables showing how it varies for fuels of different character. The method of calculation is shown by means of examples.

Calorific Power of Combustible Gases.—The results are given by Berthelot* and Matignon of a series of experiments made with a

* *Comptes Rendus de l'Académie des Sciences*, vol. cxvi. p. 1333.

view to ascertain the calorific power of various gases. The bomb calorimeter was employed in these experiments, and the results referred to were as follows:—

Gas.	Heat of Combustion. Calories.	Heat of Formation. Calories.
Hydrogen, H_2	690	...
Carbonic oxide, CO	682	+ 261
Methane, CH_4	2135	+ 187
Ethane, C_2H_6	3723	+ 253
Acetylene, C_2H_2	3157	- 581
Aethylene, C_2H_4	3412	- 146
Propylene, C_3H_6	4993	- 94
Propane, C_3H_8	5284	+ 305

In calculating the heat of formation the carbon was considered as diamond, and the formula was consequently—



If, however, Berthelot's value for amorphous carbon is accepted, then—



And the following figures result:—

Gas.	Calorific Value of		Heat of Formation.
	The Compound.	The Elements.	
Carbonic oxide	682	976	+ 294
Marsh gas	2135	2356	+ 221
Ethane	3723	4022	+ 299
Acetylene	5284	5688	+ 404
Aethylene	3157	2642	- 515
Propylene	3414	3332	- 80
Propane	4993	4998	+ 5

These results are for constant pressure.

II.—COAL.

The Midlothian Coal Basin.—A description of the Midlothian coal basin, together with a map of the district showing the outcrops, is given by R. Martin.* The stratification is irregular, dipping at 50° on the west, and then rising gently towards the eastern side. The dif-

* *Transactions of the Federated Institution of Mining Engineers*, vol. vi. pp. 388-392, with two plates.

ferent seams and faults are briefly mentioned, and the output is given as about a million tons per annum. Longwall working is mostly used and the seams are fairly free from gas. As an appendix the names of the seams are given in order at the various localities.

The Coal Resources of Carinthia.—A. Tschebull * is of opinion that carefully planned explorations would undoubtedly result in the discovery at great depths of thick seams of bituminous coal and lignite. The Carinthian coal-measures are well marked by characteristic fossils, and cover a fairly extensive area, which appears to be smaller than it really is owing to its being in places overlain by more recent formations. The area is described by the author, with the aid of a map. It is interesting to note that the lower beds of the coal-measures contain thick beds of iron ore, notably at Turrach, Krems, and Leobengraben.

The Tertiary formation contains seams of brown coal, which are of considerable industrial importance. The production has, however, decreased 30 per cent. since 1883. The condition of the brown-coal industry of Carinthia is indicated by the following statistics :—

	Average, 1882-1891.	Maximum.		Minimum.	
	Tons.	Year.	Tons.	Year.	Tons.
Produced	77,180	1883	93,040	1889	58,860
Imported	58,370	1888	86,060	1882	28,320
Consumed	135,550	...	...	...	...
Exported	76,600	1890	115,670	1882	41,910
Total	212,150	...	...	...	...
Imports and exports . .	134,970	...	...	...	...

The maximum production, it will be observed, almost coincides with the minimum importation, and, conversely, the minimum of production coincides with the maximum importation. There is an undoubted demand for coal in the country. If, therefore, the coal-mines were economically worked on a large scale, the production would be readily absorbed, and coal could even be supplied in Tyrol and Italy at a lower rate than is possible with more distant collieries.

The Dux Brown-Coal District.—H. Engelhardt † gives a histo-

* *Berg- und Hüttenmännisches Jahrbuch der k. k. Bergakademien*, vol. xlii. pp. 51-66.

† *Nova Acta der ksl. Leop. Carol. deutschen Akademie der Naturforscher*, vol. lvii. pp. 131-219, with 15 plates.

rical sketch of the development of the mining industry at Dux, in Bohemia, and describes the geology of the district. Above the coal-seams are clays and shales, the former being traversed by a parting of sphærosiderite. The principal material for the formation of the coal appears to have been derived from bog plants and from the stems of the two conifers very abundant in Tertiary times—*Taxodium distichum miocenicum* and *Glytostrobos europæus*. In the clays above the coal as many as 177 plant varieties have been found. The exact age of this Miocene flora is discussed by the author.

Brown-Coal in North Hungary.—Descriptions of the brown-coal deposits of North Hungary have been published.*

The Handlova basin comprises seven seams of brown-coal, one of which is nearly 4 yards in thickness, with coal of a black colour, hard, and of a conchoidal fracture. Mining is carried on merely on a small scale, thirteen miners being employed. A similar, but less extensive, deposit occurs at Aranyosch-Maroth, with two seams 2 to 4 feet in thickness. Two small collieries are working in this district.

The northern edge of the Hungarian Tertiary basin is richest in brown-coal, and mining is conducted on an extensive scale, notably at Salgo-Tarjan, where 1030 miners are employed, and 360,000 tons of coal are raised.

The Steierdorf Coalfield in the Banat.—The discovery of coal in this district was made by a woodcutter in 1790.† By 1809 coal-mining was beginning to be an active industry in this field, but up to 1830 the total output of coal did not exceed 119,000 tons. About the year 1827 the possibility of utilising the coal for conversion into coke had become generally recognised, and as the coke so obtained in open heaps was of good quality, mining for coal, which had been allowed to fall into abeyance, was again carried on actively. In 1840 the annual output had risen to 9600 tons, the total quantity produced up to that date having been 197,200 tons, most of which had been converted into coke. It had only been found possible, however, to use the lump coal for this purpose, and the smalls had mostly been thrown on the waste-heaps. The coke was used largely at the Oravicza and Cziklowa smelting establishments, and details are given as to the prices and conditions under which the works purchased this coke.

* *Glückauf*, vol. xxx. pp. 5-7.

† *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xli. pp. 620-622, 627-630.

The production of coal slowly increased after 1840, and various important mining works were undertaken with a view to a large increase in the output, including one very long adit. These had the effect of increasing the annual output from 28,000 tons in the period 1846-55, to 46,500 tons for the period 1855-60. Then railway communication began to be opened up; and in 1865 the annual output of coal had risen to 119,380 tons, while in 1890 it amounted to 253,000 tons, or about five times as much as it was in 1855.

Belgian Cannel Coal.—A. Firket * gives some notes on some specimens of cannel coal and bituminous shale obtained from Belgian collieries. The following results were obtained on assay :—

Colliery.	Volatile Matter.	Fixed Carbon.	Ash.
	Per Cent.	Per Cent.	Per Cent.
La Haye	11·56	51·11	37·33
Bois d'Avroy	16·83	40·95	42·22
Horlos	12·31	71·40	16·29
Espérance	40·35	57·68	1·97
Marimont	50·56	46·82	2·62

Coal in South Russia.—In a pamphlet covering 56 pages, A. Ernst † discusses the mineral resources of the Donetz region of South Russia. The coal-mining industry dates from 1852. The coals range from anthracite to non-caking bituminous varieties, with, on an average, 34·43 to 39·93 per cent. of volatile constituents, 53·51 to 81·25 per cent. of fixed carbon, and 3·89 to 11·74 per cent. of ash. In 1890 the Donetz region produced 3,001,800 tons of coal, including 597,624 tons of anthracite.

Iron ores are widely distributed throughout the carboniferous strata. They comprise brown iron ores, sphærosiderite, bog iron ore, and, more rarely, blackband. The proportion of iron varies from 10 to 57·6 per cent., the average being 36·15 per cent.

Russian Coals.—H. von Jüptner ‡ quotes the following data given by W. Alexeieff as to various Russian coals and lignites :—

* *Annales de la Société Géologique de Belgique.*

† *Die mineralischen Bodenschätze des Donezgebietes*, Hanover, 1893.

‡ *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xli. pp. 434-435

Origin.	Percentage Composition.				Yield of Coke.	Calorific Power.
	Carbon.	Hydrogen.	Oxygen.	Nitrogen.		
					Per Cent.	Calories.
Gangul.	78.27	4.46	16.31	0.96	62.7	7302
Tkwebuli (Caucasus)	78.42	5.13	15.41	1.04	57.2	7525
Sosna (Altai)	78.90	5.61	13.05	2.44	59.0	7600
Werchne Gubach (Ural)	82.56	5.44	11.04	0.96	62.1	8116
Saghalin Island	83.57	5.50	9.10	1.83	64.6	8207
Rutschenkowo (Donetz)	83.23	5.01	10.06	1.70	71.7	8230
Kamensk Works	90.28	4.90	3.82	1.00	85.2	8200
Kirghis Steppes, black lignite . .	60.42	4.00	35.15	0.43	29.9	4860
brown lignite . .	62.79	5.56	31.39	0.26	33.6	5875
Riawan, boghead	70.00	8.56	20.59	0.85	13.6	8595
Tula	77.38	10.14	18.82	0.66	19.9	9104

Coal Deposits in Northern Spain.—L. Mallada gives a geological sketch* of the country traversed by the mineral railway from La Robla to Valmaseda, from the northern part of Leon to the Cantabrian Cordillera. In the first half of its course, this railway opens up some important coalfields. The coal-seams exist in Devonian, Silurian, and Cambrian horizons, associated in places with the lower carboniferous strata or with the mountain limestone, which latter is known to contain, in the Cantabrian Cordillera, numerous mineral veins carrying chiefly copper, cobalt, and zinc. The Cambrian strata are of very small extent, and the Silurian are not of much greater area. The Devonian horizon is far more prominent. Twenty or thirty outcrops of coal have been observed. There are, however, in reality only eight or ten seams, which, by a double fold in the strata, appear to be doubled or trebled in number. The seams are all very highly inclined, and some are of considerable thickness. Three coal basins have been observed, in each of which there are about the same number of seams.

The Coalfields of Castille.—R. Oriol † observes, that the approaching opening of the railway from La Robla to Valmaseda is of especial importance in connection with the coalfields of Castille. These are briefly described. In tabular form a statement is given, showing the geological horizon to which each of the known deposits belongs. These divisions, the author observes, are perfectly distinct, both stratigraphically, chemically, and palæontologically. The majority of the groups which correspond in the Asturias to the upper coal-measures, rest upon beds older than the coal-measures at Ferofies and Anao, upon Devonian

* *Revista Minera*, vol. xlv. pp. 41-43.

† *Ibid.*, pp. 89-91, 113-116.

rocks, and at Tineo, Bangas de Tineo, and Tormaleo, upon Cambrian slates. The geological character of the various coal-measures is considered, and their palæontological characteristics are also passed in review, the various fossils being given which are of most frequent occurrence.

The author then proceeds to give Gruner's classification of coals, and adds the following table descriptive of the coals mined by the Coal and Smelting Company of Asturia:—

Origin.	Free from Ash.		Calorific Value.	Ash.
	Fixed Carbon.	Volatile Matter.		
	Per Cent.	Per Cent.	Calories.	Per Cent.
Mosquitera	60·05	39·95	6176	3·60
Sama	62·40	37·60	6345	2·50
Maria Luisa	64·40	35·60	6738	2·55
La Justa	68·00	32·00	7214	2·40
Santa Bárbara	76·11	23·89	7320	3·12
Coto de Aller	83·20	16·80	7841	5·14

The last coal is of the non-caking anthracitic type of Gruner's classification. These various coals are all from the same field, but from various points, and the great varieties in their character the author attributes to metamorphic influences.

In the northern part of the province of Palencia, and bordering on that of Santander, a local deposit exists on the River Rubagon, which deposit is also known by the name of the Santullan Valley. It is the first that is met with when travelling from east to west on the new line of railway from La Robla. This deposit is, however, already connected by a short line of railway with the Santander line at Quintanilla de las Torres. The coal-mines of this field are the oldest and most productive of any in Castille. The field extends from Alto de Terena, where it is covered by Triassic beds, to Campomayor, where it again disappears under Triassic rocks. This coalfield has a known length of about six miles, with a breadth of about a mile. At the south the coalfield again appears covered by Triassic beds, which in turn pass below Liassic limestones. Devonian quartzites are observable to the east of the valley, between the coal-measures, which rest on the mountain limestone. There are two known groups of coal-seams in this district, separated from each other by a barren zone of two-fifths of a mile in width. In the lower zone nine seams are worked, varying in thickness from 2 feet to over 6 feet. In the upper group there are four seams, although one of them is of no commercial value. Assays made at the laboratory of

the Madrid School of Mines, show the composition of the coals of the Barruelo mines of this field to be as follows :—

Free from Ash.		Calories.	Ash.	Coke.
Fixed Carbon.	Volatile Products.			
71·39-83·26	28·61-16·74	7323-7852	1·90-13·08	73·2-83·95

The coal which showed the highest calorific value, 7852 calories, had the following composition :—

Free from Ash.		Ash.	Coke.
Fixed Carbon.	Volatile Products.		
79·14	20·86	7·25	80·65

It was from the Barbara colliery, from seam No. 8. Assays are given of the coals of each seam in this district, and also in the Orbó portion of the field. Here the coal, considered as free from ash, contains, as its lowest percentage of fixed carbon, 68·75, in seam No. 4; the maximum percentage, 80·95, being observed in the case of the coal from seam No. 3, at the Estrella de Elena colliery, the volatile products being respectively 31·25 and 19·05 per cent. Of seam No. 3, however, another assay is also given. This is from the San Ignacio colliery, where the seam yields only 75·51 per cent. of fixed carbon, though its calorific value has increased from 7359 calories to 7953. The cost of production is stated to be as follows :—

	s.	d.
Rough coal	9	0
Washed coal.	10	0
Briquettes	13	0
Coke	16	9

The coal-mines of this field are exposed to considerable competition; and at the time that the article was written, it was rumoured that many of them were about to be closed down.

Coal in Victoria.—J. Stirling * has drawn up, for the Department of Mines, an exhaustive report on the Victorian coalfields. It deals specially with the Gippsland carbonaceous area, and describes the occurrence of coal at Kilcunda, Adam's Creek, Fish Creek, Darnum district, Upper Tarwin Valley, Conobea's Selection, Outtrim, and Foster. It is illustrated by means of twenty plans and sections printed on folding plates.

An official report† has recently been published in Victoria, dealing with the economic value of the coals produced in that colony. The

* "Reports on the Victorian Coalfields," Melbourne, 1893.

† *Colliery Guardian*, vol. lxxvii. p. 223.

tests chiefly relate to the value for railway work, but they also include calorimetric determinations. The following coals were tested:—Newcastle, Jumbunna, Coalville, Coal Creek, North Coalville, Korumburra and Jeetho, Outtrim, Strzlecki, Kilcunda, Coal Creek Extended, and Hazelwood. In most cases the large amount of ash and the clinkering render these coals unsuitable for general work. The first two named are, however, suitable, and to a less extent Coal Creek coal also.

Coal in New South Wales.—A seam of coal which has been proved at various depths is now known to extend over a very large area of the coast district of New South Wales.* It has been found at Port Jackson. A bore-hole that was put down struck the seam at a depth of 2801 feet, and a body of "burnt coal," 8 feet in thickness, was discovered. Another bore-hole has now shown that this alteration, due, it is thought, to volcanic action, is quite local. The second bore-hole struck the seam at a depth of 2917 feet. The seam was bored through in a further depth of 10 feet 3 inches. With the exception of a thickness of 13 inches, Professor David, of the University of Sydney, states that the coal is of good quality, being a useful splint and bituminous coal. The roof is described as a clay shale, while the floor is a black carbonaceous clay shale containing impressions of the fossil plant *vertebraria*.

T. W. E. David † reports on some of the principal deposits of kerosene shale in the neighbourhood of Doughboy Hollow, near Murrurundi. The total area of unworked shale appears to be 25 acres. The total thickness of the seam varies from 3 feet 2 inches to about 5 feet 8 inches. A small portion of this thickness in the lower part of the seam, from 12 to 14 inches in thickness, is shale of fair marketable quality, yielding about 60 per cent. of volatile hydrocarbons. An average thickness of 4 feet of shale of inferior quality extends over the whole area; its average composition is as follows:—

Moisture.	Volatile Hydrocarbons.	Fixed Carbon.	Ash.
2·00	34·00	6·00	58·00

Coal in Canada.—R. G. McConnell‡ reports that lignite was found in the Athabasca district in the Peace River sandstones, but in seams too small to be workable.

* *Australian Mining Standard*, vol. ix. pp. 652 and 659.

† *Annual Report of the Department of Mines, New South Wales*, 1893, pp. 159–163.

‡ *Annual Report of the Geological Survey of Canada*, vol. v. Report D.

J. B. Tyrrell * states that lignite was found in North-west Manitoba, in the Benton shale on Swan River. It has a wood-like structure, and on analysis yielded—

Hygrescopic Water.	Volatile Matter.	Fixed Carbon.	Ash.
9·66	43·16	43·61	3·57

H. Fletcher † describes in detail the coal-deposits of Pictou and Colchester counties, several of which are of considerable economic importance.

G. C. Hoffmann ‡ gives the following results of an assay of semi-anthracite from the Main Red Deer River, British Columbia.

Volatile Matter.	Fixed Carbon.	Ash.
13·98	81·94	4·08

The discovery of a coal-deposit has been reported on the boundary between Manitoba and Minnesota, close to the Lake of the Woods. The bed is said to extend across the frontier into Canada. The coal is stated to be a soft coal of good quality.§

Indian Coal.—The Government of India has published for the use of the Imperial Institute,|| as one of the handbooks of commercial products, a valuable treatise, covering seventy-seven pages, containing a summary of the available information with regard to the occurrence and working of coal in India. The first section deals with the geology of the coalfields, statistics, fuel consumption on railways, and labour. The second section contains a detailed account of the working collieries, whilst the third section describes the coalfields of prospective importance. The volume is illustrated by a large map of India, showing the railways and coalfields on a scale of 1 inch to 96 miles.

The Singareni Coalfield.—A general account of the Singareni coalfield, Hyderabad, India, is given by J. P. Kirkup.¶ This field was discovered in 1872 by Dr. King, but active work did not begin until 1887. It is already provided with railway communication and further railways are being built. The country is thickly overgrown with jungle

* *Annual Report of the Geological Survey of Canada*, Report E.

† *Ibid.*, Report P.

‡ *Ibid.*, Report R.

§ *Toronto Monetary Times*, January 26, 1894.

|| *Imperial Institute Series*, No. 9. Indian Coal. Calcutta, 1893.

¶ *Transactions of the Federated Institution of Mining Engineers*, vol. vi. pp. 421-448, with one plate.

and scantily populated. The field is a small outlier of the great deposit of coal-measures found in the Godavery valley, and includes representative beds of the Lower Gondwana system. About nine square miles contain coal-bearing beds. Sections of the field are given as shown by a number of bore-holes and shafts, and the faulting is also considered. The seams of coal, in descending order, are, first, the thick coal, consisting of 30 to 50 feet of alternating coal and shale. Next comes a variable seam, 2 to 5 feet in thickness, 100 feet below the thick coal, and this is followed 35 feet deeper by a seam 2 to 9 feet in thickness. The lowest, or King seam, is a hard, semi-bituminous coal, 3 to 7 feet in thickness. The upper seams have not been much explored and are of but little value. An analysis and assay of coal from the King seam shows—

	Per Cent.		Per Cent.
Carbon . . .	66.45	Volatile matter . . .	25.25
Hydrogen . . .	4.19	Coke—	
Oxygen and nitrogen .	10.61	Carbon . . .	56.50
Sulphur . . .	0.45	Ash . . .	10.65
Water . . .	7.60		67.15
Ash . . .	10.70	Water . . .	7.60
	100.00		100.00

This coal will not coke. It burns freely without the ash clinkering, and evaporates 7 lbs. of water per lb. of coal. It is liable to spontaneous combustion. At present this seam is opened out by inclined workings, with a shaft for ventilation. An incline is driven through the superincumbent measures, and workings are opened on either side on the pillar and stall method. The roof is good, and a large proportion is won in the first instance, but working in the broken has not been prosecuted to any extent. Not much water is met with, but it is troublesome in dip workings. Naked lights are in general use. The rate of advance is very slow compared with an English standard, and a large number of men are required to give any considerable output. Six inclines are at work and one shaft. Particulars are given of these and of the general work. The author then deals with the labour question, with the markets, and with the costs and output, in some detail.

The Tendau-Kamapying Coalfield.—In a geological report on the Tenasserim Valley, P. N. Bose * shows that there is coal of two different ages in that locality, one belonging to the Carboniferous group, and the other to the Tendau-Kamapying group, which in all probability

* *Records of the Geological Survey of India*, vol. xxvi. pp. 148-164, with two maps.

is of Tertiary age. The Carboniferous coal is far more widely distributed than the Tertiary, but is economically worthless. The Tertiary coal occurs at two localities—Cha Mitive (Tendau) and Kamapying, both situated on the western bank of the river Tenasserim. It has never been found on the eastern side, and there are considerations which make its occurrence there very unlikely. The available quantity of coal at Kamapying is estimated at 600,000 tons, and that at Cha Mitive at 380,000 tons. For steam purposes the coal is far above the average of Indian coals.

As regards thickness and quality, the coal on the Heinlat at Kamapying is the most promising in the whole field. It is in very thick deposits, and is almost free from iron pyrites. There are some 300,000 tons of coal of this type. The expenses of working would amount to 5 rupees per ton, and the cost of transit to Mergui would be about 2 rupees per ton.

Coal in California.—W. Ireland* gives reports on the occurrence of coal in California. In Humboldt county small seams of coal have from time to time been discovered, but a seam recently opened at Maple Creek is the most promising yet noticed. The mineral appears to be a lignite of Pliocene age. On assay it yielded—

Moisture.	Volatile Matter.	Fixed Carbon.	Ash.
16.25	44.50	31.50	7.75

In Amador county borings show a large amount of lignite, as yet untouched, which must eventually find its way into the market. The physical appearance of this fuel from the Newman ranch (Assay I.) is quite different from that mined near Ione (Assay II.). The results obtained on assay are as follows:—

	Moisture.	Volatile Matter.	Fixed Carbon.	Ash.
I. . . .	13.25	49.00	27.25	10.50
II. . . .	15.00	37.75	38.50	8.75

In 1891 workings were commenced on the outcrop of a coal-seam near Sulphur Creek, in Colusa county. The coal had the following composition:—

Moisture.	Volatile Matter.	Fixed Carbon.	Ash.
7.00	29.75	48.00	15.00

The Wellston Coal District in Ohio.—J. A. Ede† has made a careful investigation of the Wellston coal district of Ohio, and finds

* *Eleventh Report of the State Mineralogist of California*, Sacramento, 1893.

† *Engineering and Mining Journal*, vol. lvii. pp. 126-127.

1894.—i.

that it presents some structural features worthy of consideration. Contiguous to the line of the old survey from Fluhart No. 2 to Jackson, there is a structural peculiarity common to the mines worked in that locality. The fact of finding no coal in some of the bore-holes does not always show that the margin of the coalfield has been reached. The Wellston coalfield is not exhausted. There are large areas to the east and north still undeveloped.

The Coal-Mines of West Virginia.—In coal output, West Virginia ranks fourth in importance among the coal-producing States of America, being preceded in this respect by Pennsylvania, Illinois, and Ohio. A. Peel * points out, however, that the industry is only in its infancy, and that one-thirteenth of the aggregate total coal area is contained within her borders. It may, consequently, be said that this State outranks all others in the extent and value of the coal-beds, which are easily mined, of the highest grade of excellence, in close proximity to large deposits of iron ore and limestone, and accessible to the best markets.

In his exhaustive report, covering twenty-two pages, the author discusses in detail the character of the country and of the coal, the thickness of the seams, the system of mining, the absence of fire-damp, ventilation, inspection of the mines, the number of miners, the wages paid, prices, rates of transport, and amount of coal exported. An analysis by J. Pattinson, of Pocahontas, Flat-top, semi-bituminous coal gave the following results :—

C.	H.	O.	N.	S.	Ash.	H ₂ O.	Total.
86.51	4.44	4.95	0.66	0.61	1.54	1.29	100.00

This coal is of high calorific power, being in this respect equal to the best Welsh steam coal.

The author is of opinion that a considerable increase in the production of coal from this region may be looked for in the future, and that, although there would not appear at present to be any danger of the markets of the United Kingdom being flooded, as has been rumoured, with supplies from West Virginia, there are conditions which tend possibly in the direction of the establishment of trade relations of such a nature abroad as may result in a great development of the export of coal from the United States.

Coal in Washington Territory.—R. Volkmann † states that

* *Foreign Office, Miscellaneous Series, Report No. 321, March 1894.*

† *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xli. p. 644.

samples of coal from Pierce county, Washington, gave on assay the following results:—

No.	Fixed Carbon.	Combustible Gases.	Moisture.	Sulphur.	Ash.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
1.	60·96	28·74	0·35	...	9·59
2.	61·58	28·99	2·43	0·06	6·94
3.	64·00	28·00	2·24	...	5·76
4.	68·38	19·30	0·47	...	11·83

The Coalfields of Sonora, Mexico.—J. Overend * describes the coalfield of Sonora, Mexico. Anthracitic coal occurs in four seams, ranging from 1 to 5 feet in thickness, in the valley of San Marcial, but in most cases they are highly affected by volcanic disturbances. At San Xavier two seams are exposed high in the hills, the thicker one being $4\frac{1}{2}$ feet, with $2\frac{1}{2}$ feet of clean coal. In the Barrancas valley three seams have been partially opened out. These dip at 35° , and two of them show 6 and 7 feet respectively of clean coal. The author is of the opinion that no scheme of working the coal would be profitable, as the seams are so disturbed. A map and some sections of the district are given.

Argentine Coal.—The following are assays of coal from two of the provinces of the Argentine Republic:†—

Description.	Neuquen.	Juan.
	Per Cent.	Per Cent.
Moisture	9·05	2·05
Volatile products	33·50	49·51
Fixed carbon	53·90	47·81
Ash	3·55	0·63
Sulphur	traces	traces

Coal in Brazil.—Borings conducted by W. Calderwood ‡ at Taubaté, São Paulo, Brazil, have shown the presence of extensive coal-beds at a depth of 60 to 80 yards. This is the first recorded discovery of coal in Brazil, and, if the coal proves to be of satisfactory quality, it will be of

* *Transactions of the Federated Institution of Mining Engineers*, vol. vii. pp. 230–233.

† *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlii. p. 21.

‡ *Chemiker Zeitung*, vol. xviii. p. 89.

great industrial importance, seeing that at the present time imported coal is sold in São Paulo at £6 per ton.

Coal in the Republic of Colombia.—D. Bellet* summarises what is known of the deposits of coal in the Republic of Colombia, basing his notes chiefly on the reports to the bureau of the American Republics, especially those by Caracristi. Near Colon, in Panama, one of the first seams found was 3 feet in thickness, and showed 40·13 per cent. of carbon, 30·21 of ash, and 12·96 of water. Other beds have been found to crop out in the same department, from 3 to 6 feet in thickness, and covering an area of nearly 100 square miles. In the department of Canca some twenty seams of bituminous coal and lignite are found over an area of 7000 square miles. Two samples show:—

Specific Gravity.	Fixed Carbon.	Ash.	Volatile Matter.	Water.	Sulphur.
1·62	41·50	6·11	50·33	2·06	...
1·81	77·52	7·31	12·41	2·50	0·26

More to the east, in the department of Magdalena, lignite containing cannel coal is found. In some places this is of good quality. Coal is also found in other departments, but the consumption in the country is small. The steamers leaving the country use nearly 41,000 tons of coal yearly.

Coal in Honduras.—R. F. Gosling, in a recent consular report,† refers to the progress of mining in Honduras. Brown coal is stated to be plentiful on the north coast, and a seam of anthracitic coal, 5 feet in thickness, is said to have been discovered near La Ceiba, on the Atlantic coast. Coal-deposits in this country are the exclusive property of the State.

Coal in South Africa.—Of the coal placed on the market at Johannesburg, that obtained from the Middleburg district is considered by far the best. On the other hand, the coal obtained from the Boksburg collieries is of a peculiar character, and is known as “drift” coal, it being believed that it represents coal secondarily deposited from the original denuded seams. In some places in the Middlesburg district large deposits of iron ore are also found.‡

Coal in Persia.—A. F. Stahl§ observes that all the coals hitherto found in Persia are of Jurassic age, like those of Tkwibuli in the

* *Le Génie Civil*, vol. xxiv. p. 263.

† September 30, 1893, through the *Colliery Guardian*, vol. lxvi. p. 964.

‡ *The Standard and Diggers' News*; *Australian Mining Standard*, vol. ix. p. 644.

§ *Chemiker Zeitung*, vol. xvii. p. 1596.

Caucasus. Such coals exist in nearly the whole range of the Elburz Mountains. The sedimentary deposits are very regular, and the coals are easy to mine. Wherever in the Elburz Mountains an outcrop of Jurassic limestone is observable, it is almost safe to conclude that at a depth of 700 or 800 feet coal will be found below.

Coal has long been mined in the neighbourhood of Teheran. To the north of the Teheran and Kasvin post road lie the mines of Abijek, Tschamburek, Chio, Chur, and Feschend. Of these the Chio colliery is the most important. Here sixteen seams are known, of which six are worked. These vary in thickness from 2 to 4 feet. To the north-east of Teheran, between the watersheds of the Lahr and the Djudjerud, coals are mined along the southern slopes of the mountain range at a number of places named by the author. The coal mined is of a very variable character, and usually decrepitates rapidly when exposed to atmospheric action. Some samples which the author has examined were as follows :— (1.) This sample consisted of 30 per cent. of good bituminous coal, and of 10 per cent. of a non-caking coal, while the remaining 60 per cent. was a black incombustible shale. (2.) Ten per cent. caking coal, and 90 per cent. non-caking coal. Dry distillation showed 80 per cent. of non-coherent fixed carbon, and 20 per cent. of volatile products. (3.) A short-flamed non-caking coal, yielding 19 per cent. of volatile products, while the residue contained 50 per cent. of ash. (4.) A caking coal, yielding 31 per cent. of volatile products and 69 per cent. of coke. This coke contained 9 per cent. of ash. (5.) Ten per cent. caking coal, mixed with 90 per cent. of a non-caking coal. Dry distillation gave 28 per cent. of volatile matter, and 72 per cent. of a slightly caked coke. This carbonaceous residue contained 27 per cent. of ash. (6.) A caking coal, which yielded on dry distillation 27 per cent. of volatile products, and 73 per cent. of a coke containing 10 per cent. of ash. These are the kinds of coal which are sold in the Teheran market. The method of mining is solely the most primitive form of open-cast. Other deposits of coal and brown-coal are also referred to.

Coal in Yezo.—A. H. Savage Landor * notes several occurrences of coal in the Island of Yezo, which is the largest of the Hokkaido group belonging to Japan. On this island are the Poronai coal-mines, distant about forty miles from the west coast, and connected with it by a railway. On the eastern coast, coal of varying quality and lignite appear in Tertiary strata, and these have been worked to a limited extent. A considerable

* "Alone with the Hairy Ainu." London, 1893.

amount of coal is also worked in the south and taken by mules into Hakodate.

Vanadiferous Coal.—A. Mourlot * has investigated a coal analogous to that recently described by J. J. Kyle,† from the province of Mendoza, in the Argentine Republic. Its specific gravity is only 1·15 to 1·2. It contains—

Ash.	H.	N.	C.
0·63	4·73	1·67	85·03

The composition of the portion of the ash soluble in acids is as follows :—

V_2O_5 .	SO_3 .	P_2O_5 .	Fe_2O_3 .	Al_2O_3 .	CaO .	K_2O .
38·5	12·1	0·8	4·1	4·0	8·44	1·8

And that of the portion insoluble in acids is

SiO_2 .	Al_2O_3 .	Fe_2O_3 .	MgO .
13·6	5·5	9·4	0·9

The proportion of vanadic anhydride in the original coal is 0·24 per cent.

Utilisation of Peat.—A report by a Swedish commission appointed in May last, to deal with two proposed methods for treating peat, has recently appeared.‡ In the first method, the peat is distilled in closed chambers at temperatures between 225° C. and 260° C. Under 220° the process proceeds too slowly, and above 260° C. inflammable gases are produced. The cost of the finished material was found to be equal to that of coal. The other process is that of Ekelund, in which the peat is dried in three superimposed chambers. This is similar to several previous kilns, and the product is expensive. Dried peat dust, it was found, can be used as fuel with success.

Some experiments have recently been made near Bridestowe, Devon, for the utilisation of peat by the method of J. D. Brunton. The peat is pressed through a perforated plate, to reduce it to the consistency of clay, and is then pressed into bricks by moulding machines. The bricks are subsequently dried in a kiln, losing six-sevenths of their weight.§

At a meeting of the Civil and Mechanical Engineers' Society,|| a paper on peat was read by R. Nelson Boyd. After alluding to the formation of peat in nature, its origin, localities, and characteristics, the author referred to its antiseptic qualities and the valuable products obtained from it by destructive distillation. Its great value, however, lay in the

* *Comptes Rendus de l'Académie des Sciences*, vol. cxvii. pp. 546-548.

† *Journal of the Iron and Steel Institute*, 1893, No. I., p. 219.

‡ *Teknisk Tidkrift*, 1894, pp. 29-41.

§ *Industries and Iron*, vol. xv. p. 755.

|| *Ibid.*, vol. xvi. p. 119.

possibility of converting it into a useful fuel. The author then described some of the machinery in use for preparing peat for fuel in different countries, and mentioned the reports made on the value of peat to Government in this country, as well as the results obtained in practical experiments on railways and steamers. After giving various analyses of peat and its products, the author described the system invented by Mr. Blunden, by which the peat is forced out of the machines used, in the form of thick drain tiles or tubes. Mr. Blunden's general process was then described, and the cost of his plant stated. The economic value of peat was considered, first as a fuel, secondly as to the products from it by distillation, and thirdly as to the coke or charcoal produced. At present the two latter have a value in the markets, as the distillation produces a fair amount of ammonium sulphate, and the coke or charcoal has a special value owing to its freedom from impurities. It was also pointed out that eventually the large deposits of peat will have a greater value as the cost of coal increases, which it must do in course of time.

III.—COKE.

American Coke.—H. Wedding* observes that the West Virginia coke now largely competes with that of the Connellsville region. The quantity of coke made in Pennsylvania amounted in 1891 to 10,483,000 tons, as compared with 1,856,000 tons made in West Virginia, 1,745,000 tons in Alabama, and 653,000 in Tennessee, the other States producing between them 134,000 tons. The coal of the Connellsville field of Pennsylvania contains, on an average :—

Water.	Volatile Matter.	Fixed Carbon.	Sulphur.	Ash.
1.130	29.812	60.420	0.689	7.949

Occasionally the composition varies largely from this, shale from the roof often finding its way into the coal when the method of mining has been faulty. The coal is not broken down or picked in any way, but is sent in waggons holding from 1 ton to 2 tons direct to the ovens. Of these, at the date to which the author refers, there were 17,250, distributed among eighty-five groups. Each coal-miner raises about 8 tons of coal in the 9-hour shift, the seam of coal worked being about 9 feet thick. The beehive ovens in use vary from 10 feet 6 inches to 12 feet in diameter, and from 5 to 7 feet in height in the

* *Stahl und Eisen*, vol. xiii. p. 923.

clear. In the larger ovens a little over 4 tons is coked in the 48-hour shift, or 6 tons in the 72-hour period, the average returns of coke being 67 per cent. The following shows the average percentage composition of the coke made :—

Water.	Volatile Matter.	Fixed Carbon.	Sulphur.	Ash.
0.70	0.88	89.51	0.71	8.83

The ash, however, is usually higher than this, averaging from 9.75 to 10.0 per cent. The 17,250 coke ovens of the district require daily 35,000 tons of coal and 6,000,000 gallons of water. When it is desired to make foundry coke for cupola purposes instead of blast-furnace coke, the coking period is increased from 48 hours to 72 hours. By the longer duration of the coking period a harder coke results, which also breaks into larger pieces. The outer portions of the coke are not used for foundry purposes.

The coal of the West Virginia field is extremely pure. In the north-eastern portion of the field only one seam of a useful degree of thickness occurs, but the coal yields a coke of very good quality. On the New River there are three such seams, which vary in thickness from 3 to 5 feet; but further south, again, in the Pocahontas district, there is only one workable seam, though its thickness is as much as from 6 to 10 feet.

The Flat Top coal of West Virginia has the following composition :—

Water.	Volatile Matter.	Fixed Carbon.	Sulphur.	Ash.
1.01	18.81	74.26	0.73	5.19

while the coke produced from this coal yields :—

Water.	Volatile Matter.	Fixed Carbon.	Sulphur.	Ash.
0.35	0.76	92.55	0.60	5.75

The percentage of ash is variable, but is always very low, coke from the unwashed coal occasionally containing as little as 2 per cent. of ash. It is little to be wondered at, therefore, that the coke industry of this district is making enormous progress. Beehive ovens are used, and into these the coal is charged without any preliminary preparation.

The North-Western coalfield is that of the New River district, largely in Fayette county. In this field in 1892 the quantity of coal raised amounted to 1,564,579 tons, while the coke made was 680,216 tons. The coal-seams worked occasionally reach a thickness of 7 feet. Here, too, the coal is usually very free from ash, various samples showing from 2.10 to 6.92 per cent.

The Fairmont field lies to the north-east. In this district the coal is a semi-bituminous variety. Still a considerable quantity of coke is made

from it in ovens of the beehive type, and the following assay shows its average composition :—

Water.	Volatile Matter.	Fixed Carbon.	Ash.	Sulphur.	Phosphorus.
0·24	1·85	91·08	6·83	0·67	0·15

The coke of the Flat Top field is chiefly used for blast-furnace and cupola purposes, whilst that of the New River and Fairmont fields is mainly employed for household use. Throughout the United States it is customary to employ ovens which are not provided with condensation plants for the collection of the by-products.

Recent Progress in Coking.—R. de Soldenhoff* describes the progress made in coking during the last few years, referring briefly to the early history of coke manufacture. The coke is now improved by crushing the coal, and only using coal fine enough to pass through a screen with holes of $\frac{3}{8}$ -inch diameter. Smaller sizes are not necessary, and indeed are not to be preferred, as some is wasted by being blown away, and the yield is also less. Washing the coal also improves the quality of the coke, as it removes the dirt. Unfortunately the removal of sulphur is not so complete. The second point of improvement is in the economy, which is attained in four ways: larger make, higher yield, reduced cost, and utilisation of by-products. The first of these, that of larger weekly out-turn, has resulted from the improved form of oven, which preserves and distributes the heat more regularly and rapidly, as in the Coppée oven. The yearly average yield in coke from the coal used cannot be exactly stated, but it may be given at an increase of 4 to 5 per cent. in the Coppée oven, as compared with the Welsh oven, whilst the weekly out-turn is nearly double. The cost of labour is also much reduced in the improved forms of ovens.

There are two ways of utilising the waste gases, for generating steam or for the collection of the by-products. In the first case, the boilers should be as close as possible to the ovens, and suitably grouped, so as to save the sensible heat of the gases, and to readily distribute them. No combustion-chamber is needed under the boilers, but a good draft and flue and chimney accommodation is required, with means for letting the gases go to waste when not required. The evaporating power of a Coppée oven is given as 184 lbs. of water per hour, equivalent to $2\frac{1}{4}$ tons of coal per week, or 8·8 horse-power per oven with good boilers. Twice the number of Welsh ovens would be required to do the same work. The gases have also been successfully used for burning bricks. Amongst the ovens

* *Proceedings of the South Wales Institute of Engineers*, vol. xviii. pp. 303–328.

arranged for the recovery of by-products, mention is made of the Jameson, Simon-Carvés, Bauer, and Solway ovens. More attention is, however, paid to the Otto-Hoffman ovens, which are a form of Coppée oven, with regenerators applied for heating the returned gases and the air used for combustion. The condensing plant used with these ovens is very complete, and it yields 3 per cent. of tar, and from 1·2 to 1·25 per cent. of sulphate of ammonia per ton of coal, besides benzol. At the same time the yield of coke is very high, as no air is admitted to the coking chamber. The cost of the plant is very great. The waste gases, after heating the ovens, are also used for raising steam. In these ovens, the coke made always contains more sulphur than that produced by other ovens, as it has no chance of being burnt out; but this may not be of such importance in view of the desulphurising processes for iron. Recovery processes cannot be applied except to caking coals of a high class, so that there does not seem to be much field for them in the South Wales coalfield.

The Manufacture of Good Coke in Spain.—In comparing the cost of production of pig iron in Spain and in the United Kingdom, attention is drawn to the fact that on the ore alone Spain has greatly the advantage, whilst in the United Kingdom the advantage lies with the coal being of such a character as to admit of the ready production of good furnace-coke. In Spain this is more difficult, and a writer in *Revista Minera* * draws attention to the Fronheiser-Price process in use at Johnstown, Pennsylvania. Here the coal is first crushed small and is then mixed with slacked lime in the proportion of about 5 per cent., or more if the coal contains upwards of 5 or 7 per cent. of ash. The mixture is then charged into the furnace in the ordinary way, and reference is made to the increase in the desulphurisation and in the quantity of ammonia yielded during the coking, while the coke is said to be of good quality.†

The Coking Process.—Greater attention has so far been paid to furnace construction, and to the utilisation of the products, than to the exact nature of what occurs during the coking process itself. The products of the coking process vary with the nature of the coal coked, with its size, the amount of water it contains, the furnace in which it is coked, and many other similar points.‡

* Vol. xlv. pp. 105–107.

† *Note by Abstractors.*—The use of lime has been frequently suggested, but it has always been abandoned after trial.

‡ *Stahl und Eisen*, vol. xiv. pp. 202–206, 255–258.

Although the mode of origin of the coal is to a certain extent explained, the chemical composition of the coal itself is still most indefinitely understood, and it has not yet proved possible to show that a coal contains definite chemical compounds, all that is really known being that coal is a combination of carbon, hydrogen, oxygen, nitrogen, and various other substances. How these are combined together is quite unknown, and it is impossible to make deductions and inferences from the nature of the material from which the coal was formed, it being unknown in what degree the ratio in which these substances existed in the original plant substance has been altered during its conversion into coal. Analysis has shown that coals which possess the same ultimate composition show among themselves very different properties. Such an analysis is therefore not adequate for deductions as to the character of the coal and the results which will be obtained from its use. The aim of the coking process is to produce a product having definite properties. It is a process in which gas is eliminated. There is consequently an absorption of heat. To obtain the desired quality of coke the coal to be coked must possess certain characteristics. In the first place, it must possess an adequate degree of fusibility, but coals with exactly the same elementary composition show very different degrees of fusibility, the one coal scarcely sintering, while the other fuses readily. The cause of the fusibility appears to lie in the presence or in the formation of certain tarry products which at higher temperatures decompose into gaseous products and solid carbon, the latter acting as a binding agent during its solidification. Coking in a crucible does not give absolutely satisfactory results, as it is self-evident that the process of coking a gramme or two must be very different from that in which several tons are treated at the same time in a coke oven. In the small crucible the coal is heated rapidly to a high temperature, the gases can escape rapidly, and the coke which results is swollen in a manner which is never observable in actual practice. The best method of ascertaining the value of a coal is to experiment with it in an actual coke oven. As a rule, the best results are obtained with the class of coal termed the bituminous coals, without being of too gaseous a character. The percentages of sulphur and ash are important; the sulphur in the coals of the Ruhr district is usually about 1 per cent. That degree of care is not always taken at collieries which should be expended on the obtaining of coal free from ash; with careful washing the percentage of ash may usually be brought down to below 4 per cent., so that a coke will result which contains a little over 5 per cent. of ash. By some it is thought that washing diminishes the

power of coal to coke on being heated, but this is certainly not true, at least, as regards the coals of the Rhenish Westphalian district.

The coking process is a twofold one. In the first place, it consists in eliminating the gaseous constituents of the coal, and in the second in converting a more or less pulverulent material, and one that is readily crushed, into a solid, compact product, that will withstand considerable stress, results which are brought about by the action of heat. The changes differ, however, with the position of the coal in the oven, whether at the sides or at the centre of the furnace. Thus, at the sides of the oven the coking process will be practically over, while at the centre of the oven some of the particles of coal still remain altogether unchanged. It follows from this that in horizontal ovens of the Coppée type, the coke formed at the sides is separated by a line following the axis of the oven, but in addition there are a number of cleavage planes running from the sides and from the bottom.

Experience shows that the frequent appearance of these planes, or their equivalent, the production of small coke, is dependent on the temperature of the oven. It may be pointed out that if one of the sides of the oven is more strongly heated than the other, the line of separation in the coke is further away from the hot side than from the cold one. The length of the coke pieces is consequently dependent on the breadth of the oven, and is half this when the temperature of the sides is equal. How slowly the coking process proceeds is evident from the time required for the central portions of the coal in a Coppée oven to turn into coke. During the coking stage there is an enormous absorption of heat, but directly the degasification of the coal has taken place the temperature of the oven rises with great rapidity.

In the beehive-shaped ovens the process is different, and no separating planes are produced in the longitudinal oven, while these exist in a modified form in the vertical ovens of the Appolt type, these planes being always vertical to the heating surface, and increasing in number as the temperature of the oven increases. To produce large-sized coke it is consequently necessary that the temperature should not rise too high.

During the coking process the charge swells considerably, and subsequently again largely diminishes in volume. The average temperature at the end of the degasification stage is about 1200°. The oven should then be discharged and refilled as rapidly as possible. Care should be taken in discharging the oven that the coke expelled does not fall in pieces too rapidly after leaving the oven, as this leads to the formation of much coke smalls. The surface on to which the coke is discharged

from the oven should be smooth, and offer but little resistance to its forward movement. To prevent the surface of the coke losing its good appearance by partial combustion, the hot coke must be immediately quenched. Some skill is required at this stage to prevent the coke absorbing water, as the coke, when cool, should not contain more than 1 per cent. If, however, the coking has been incomplete, the percentage of water retained by the coke will be far higher than this. If the water used in quenching the hot coke contains much dissolved salts, this will lead to a residue from evaporation which will altogether spoil the appearance of the coke. The percentage of sulphur is slightly diminished by the quenching process.

A most important matter in connection with the coking process is the percentage of water contained in the coal coked. This frequently exceeds even 15 per cent., and a battery of 60 Coppée ovens coking 200 tons of coal a day would thus have to evaporate 30 tons of water in that period. In some coke-works it is thought that a large percentage of water in the coal gives the best results, as tending to prevent too rapid an evolution of gas in the coking process; but the author has found, by actual experiment, that a perfectly dry and very gassy coal could be converted into good coke by suitable treatment. The decomposition of the steam by the hot coke after the earlier stages of the process are ended, leads to a loss in the yield of coke obtained. Another point with reference to the water in the coal to be coked is that, if it happens to contain much in solution, the walls of the coke-oven are apt to be rapidly attacked and destroyed.

The size of the coal to be coked is a matter of importance, as experience shows that the resulting coke is the more regular in character, the smaller and more regular in size was the coal to be coked. The best size, however, varies with the nature of the coal. Apart from the percentage of moisture present and the size of the coal particles, the furnace conditions are all important. Care must be taken that the air for the combustion only comes in contact with the gaseous products of the distillation, and never with the coal or coke itself.

The question of producing good coke from badly coking coal in admixture with other coal, or by pressure, &c., is next considered, and it is shown that these are less required when the temperature of the oven is higher. The character of the coke produced is then passed in review, and it is shown that it still contains considerable quantities of hydrogen and oxygen, the percentage of the former varying from 0.2 to 2.0, and that of the oxygen from traces up to as much as 7 per cent.

These probably exist largely in the form of some solid compounds of carbon; and it is evident that, in the case of the oxygen, the presence of much of this element must largely diminish the reducing power and combustible value of the coke. As a general rule, the quality of the coke is identical throughout the whole of the furnace charge, but some difficulty is met with near the doors, where the coking process is not aided by heat, as in other parts of the oven. The degrees of hardness and strength of the coke are directly connected with that of the temperature at which the coking proceeded, although adequate time is also necessary, experience showing that when the coking process is too rapidly completed the coke is less hard than would otherwise be the case.

The percentage of ash in the coal is a matter of great importance. The whole of this passes into the coke, and such ash is usually high in silica, alumina, and iron. These are present, as a rule, in such relative proportions as to yield a product of a high melting-point, which, by its infusibility, hinders the caking together of the charge. When the ash is high in lime, on the other hand, its action is much less deleterious, owing to the lowering of its melting-point.

The next question considered is the dry distillation during the coking process. In the early stages gas is very rapidly evolved, gradually diminishing, and finally ceasing altogether. The consequence is that it is possible, by an arrangement of the coking stages in different ovens, to obtain from a battery of ovens a gas showing considerable regularity of composition, although that taken from any two ovens would have very different compositions. The following is an analysis of such a gas:—

	Per Cent.
Carbonic anhydride	0·90
Sulphuretted hydrogen	0·40
Heavy hydrocarbons	2·33
Oxygen	0·44
Carbonic oxide	4·46
Light hydrocarbons	27·36
Hydrogen	58·37
Nitrogen	5·74
Total	100·00

From what substances these gases form it is impossible to say. It is known, of course, that the reactions commence below a red heat with the production of liquid tarry substances, which subsequently decompose at higher temperatures, beginning at about 600° and increasing as the temperature grows higher, hydrogen and carbon forming the final product. The question of the disposable hydrogen is referred to, and

then that of the formation of tar and ammonia during the coking process is also considered. The tar is a direct result of decomposition during the degasification stage. The ammonia is due to the 1 or 2 per cent. of nitrogen that is present in the coal. Only some 10 or 15 per cent. of this combines with hydrogen to form ammonia, the quantity so formed increasing with the temperature of the coking process. The presence of air must be carefully avoided, as this leads to the combustion of the ammonia. The addition of lime may increase the yield of ammonia, but it diminishes the value of the coke produced.

The Coking of Lignite, Peat, and Brown-Coal.—Professor J. Schnabegger * gives results obtained by a new process for coking peat, lignite, and brown-coal. The idea of coking these materials is not new. Attempts have been made during the last ten years at various places, notably at Köflach, but not with marked success. Eight years ago a process was patented by Hofman and Reuss for coking brown-coal, and trials were made at Fohnsdorf. The resulting coke was satisfactory and could be used for melting cast steel. No reference occurs in the English, German, or French technical literature to the coking of peat, and no experiments appear hitherto to have been made.

In the author's process, Coppée or Appolt ovens may be used, provided that the width is not too great, under 1 foot, and consequently the size of the material treated is limited. The charge of material and the yield of coke are, in view of the smaller capacity of the oven and the lower percentage of carbon, less, but the time occupied is almost always shorter than in the treatment of bituminous coal.

The following results indicate the quality of the coke :—

1. Coke from Wörschacht peat contained 60 to 68 per cent. of carbon. Calories, 5200 to 5600. Resistance to crushing, 568 to 711 lbs. per square inch. The yield varied from 44 to 47 per cent.

2. Coke from Bohemian lignite contained 72 to 75 per cent. of carbon. Calories, 6000 to 6400. Ash, 2.5 to 4 per cent. Yield, 50 to 55 per cent.

In conclusion, the author gives estimates showing that the coking of peat and lignite is financially feasible.

The Collection of Benzene on Coking Coal.—E. Donath † observes that the older methods of coking coal have now been largely replaced by

* *Berg- und Hüttenmännisches Jahrbuch der k.k. Bergakademien*, vol. xlii. pp. 45-50.

† *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xli. pp. 637-641, and 649-653.

others in which the by-products are collected. The most important improvement in this direction consists in the collection from the coke-oven gases of the benzene, which was formerly chiefly obtained from the tar produced in the manufacture of illuminating gas. With the collection of benzene and toluol, the metallurgist has approached the field of the chemical industry of organic compounds. The author considers the question of the formation of these compounds both historically and chemically, pointing out that benzene is much more stable when exposed to the action of high temperatures than are many of the hydrocarbons of simpler composition, and that it consequently forms when the vapours of these compounds are passed through red hot tubes. When the temperature to which organic compounds are submitted rises slowly, the products at first formed can distil off completely without undergoing change, but by more rapid heating these are decomposed. If, therefore, they are exhausted from the distillation as soon as possible after their formation, these distillation products are not so largely subjected to the secondary decomposition which would otherwise result. In coking, for instance, where a high temperature is rapidly acquired, the longer the products of distillation remain in the coke-oven the higher is the percentage of carbon left there. To produce much tar a low temperature is required, rising slowly, and the distillation products must be withdrawn from the oven as soon as possible. When illuminating gas is to be produced, the temperature must be rapidly raised, and the distillation products removed at once by an exhaust. It is only in recent years that the tar from coke-ovens has been collected and utilised. The conditions connected with its formation being, as has just been observed, so different from those with which the tar from gas works is connected, that the composition is naturally very different in the two cases, as will be seen from the following analyses:—

	Gas Tar.	Tar from Otto Coke Oven.
Water	2.9	2.2
Light oil, up to 200°	4.0	3.4
Aniline benzene	0.9	1.1
Naphtha	0.2	0.3
Creosote oil	8.6	14.5
Raw naphthalene	7.4	6.7
Anthracene oil	17.4	27.3
Pure anthracene	0.6	0.7
Pitch	58.4	44.4
Carbon	15 to 25	5 to 8

After a theoretical consideration of the molecular structure and

position of the various analogues of benzene, the author shows that benzene itself only occurs in very small volume in ordinary illuminating gas, an analysis showing only 0.69 per cent. by volume. The composition of another such a gas is as follows, by volume :—

H.	CH ₄ .	CO.	C ₂ H ₄ .	C ₂ H ₆ .	CO ₂ .	N.
47.0	34.0	9.0	3.8	1.2	2.5	2.5

One hundred parts of this gas coal yielded 17.04 parts of gas, 11 of gas water, and 5 of tar, and the author shows how the various organic compounds were distributed among these.

The gas obtained from a Hoffmann-Otto coke-oven had, on the other hand, the composition :—

H.	CH ₄ .	CO.	C ₂ H ₄ .	C ₂ H ₆ .	CO ₂ .	H ₂ S.	H ₂ O.
52.69	35.67	6.41	1.61	0.60	1.39	0.42	1.21

This possesses about one-half the illuminating power of illuminating gas. The first important attempt to utilise coke-oven gases as a source of benzene was probably made at the Terrenoire Works, though F. W. Lürmann has mentioned a German works as having previously done this.

The author next considers various proposals that were made for the manufacture of benzene from time to time, but more especially in connection with illuminating gas. One of these consists in subjecting the gas to a pressure of four atmospheres, when the benzene settles out in liquid form. This process, while being inapplicable in the case of gas which is to be used for illuminating purposes, is not so in that of coke-oven gases, which have only to be utilised afterwards for heating purposes. Another method which has been employed on a large scale at Middlesbrough and elsewhere, consists in passing the gas in the first instance through concentrated sulphuric acid, for the purpose of absorbing the hydrocarbons of the acetylene series, and then through a mixture of nitric and sulphuric acids, to convert the benzene into its nitro-derivatives. In this way the benzene is largely obtained in the form of its mononitro-compound, though its dinitro-derivative is also unavoidably produced. The plant required for this process is described at some length, and other modern methods are also referred to. The imports of benzene into Germany in 1892 amounted to 5683 tons.

The Gas Value of Coal.—E. Schilling* describes a small retort plant for ascertaining in a practical manner the quantity of gas, coke, and the various by-products that a coal will yield when submitted to dry distillation. The retort he employs takes a charge of 500 lbs. of coal.

* *Journal für Gasbeleuchtung*, vol. xxxvi. p. 606.

The Strachan Coke-Oven.—A. R. Strachan * has devised a flue attachment applicable to the beehive type of coke-oven. The oven is charged in the usual manner, and the charge is allowed to burn for five hours. The drawing door is then sealed, and only the inlets at the top of the oven used. The flame is then conducted along the horizontal portion of a flue, next down the continuation of this flue, and finally around the cruciform portion under the oven and out of the vertical exit part of the flue. The object aimed at is the enveloping of the charge by an even and concentrated heat.

Coke-Ovens at the Blanz Collieries.—M. Marle † describes the coking plant at the Blanz collieries. The coals used show—

Carbon	77.82	82.48
Hydrogen	5.20	3.88
Oxygen and nitrogen	10.48	6.14
Ash	6.50	7.50
Coke	63.71	83.50

The first of these is a long flaming coal, the second is anthracitic, and is mixed with the former when a dense coke is desired. Only Coppée and Appolt ovens are now used. The latter have been modified recently, especially with regard to the circulation of the gas, in order to produce a better heating effect. The arrangements for this purpose are fully described with the aid of illustrations. Since 1866 these ovens have been built of a special form of brick, like those used in glass furnaces, which reduces the labour of building and diminishes the number of joints. The ovens are now built with twenty-two compartments. Part of the gas is drawn off for lighting purposes, and it will be easy to arrange for the recovery of by-products. At present the labour in connection with these ovens is very heavy, as all the doors have to be stopped with coke dust, and the dust has to be separated on discharging the coke. To diminish the labour, the coke is now moved and screened by power. Bar screens, with bars spaced 2 inches apart, are used for separating small coke, which is further sized by a trommel into five sizes. Part of the large coke is also crushed to supply the demand for small sizes.

Coking-Plant in Nova Scotia.—W. Stein ‡ describes the coke-ovens used in connection with the blast-furnace at Ferrona, Nova Scotia. There are fifty-four ovens on the Bernard system, a modifica-

* *Engineering and Mining Journal*, vol. lvii. p. 154.

† *Bulletin de la Société de l'Industrie Minérale*, vol. vii. pp. 317-326, with plate.

‡ *Transactions of the Mining Society of Nova Scotia*, vol. ii. pp. 79-81, with plate.

tion of the Coppée oven. The internal dimensions are—length 33 feet, height $6\frac{1}{2}$ feet, mean width $23\frac{1}{2}$ inches. Each oven is charged with 7 tons of washed coal every forty to forty-eight hours. The daily output is 115 to 120 tons of large coke, a yield of 73 to 74 per cent. The ovens work in pairs, each one being charged on alternate days. A power ram is used for discharging.

IV.—LIQUID FUEL.

The Origin of Petroleum.—E. Donath* observes that, when fatty acids are distilled with superheated steam, various points of consideration result in connection with the Engler-Höfer theory as to the origin of petroleum from organic remains. Engler assumed that only the fatty substances of animate organisms took part in the formation of petroleum, and that petroleum could be formed from such substances he showed by the aid of a series of experiments. Höfer, on the other hand, considered it much more probable that the whole of the organic remains, the protein substances, should be included, and not merely the fats. This, he thinks, is probable on account of the sulphur and nitrogen which is found in petroleum, and the pyridine substances which Zaloziecki has recently observed in the oil. Some time ago, the author points out, Stas showed that when in the manufacture of stearine candles raw fatty acids are distilled with superheated steam, as much as 5 per cent. of petroleum-like hydrocarbons is produced. From these A. Cahours and E. Demarcay afterwards isolated and examined a series of substances which proved to be absolutely identical with others which had previously been separated by Pelouze and Cahours from the hydrocarbons forming the petroleum found in the United States. The author himself has frequently observed the formation of such petroleum at the last stage of the first distillation of the fatty acids. At the early stages of the distillation the smell of petroleum is not observable. The larger portion of the decomposition products of the fats remains behind in the stearine pitch that is produced, which appears to contain hydrocarbons of the paraffine series of high molecular weight. The assumption that steam at high temperatures has played a part in the formation of petroleum from corporeal fats is in accordance with the views which have been expressed on this subject.

* *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlii. p. 45.

Artificial Production of Petroleum.—C. Engler* proves that from the chemical standpoint the production of petroleum from animal remains has the greatest probability, as it is now possible to transform any animal fat into petroleum. He submitted animal fat (train oil) to distillation under a pressure of twenty-five atmospheres, at a temperature of 300° to 400° C., and found that under favourable conditions 70 per cent. of the train oil was transformed into petroleum. The same behaviour has been shown by other fats.

Petroleum in Somersetshire.—Several statements have recently been published with regard to the discovery of petroleum at Ashwick, in Somersetshire, and the locality has been investigated by B. Redwood and W. Topley, who have issued a report. Samples of water from a well showed distinct traces of oil, and slight signs were also observed at a spring in the valley. A small amount of dynamite was exploded in holes sunk in the bottom of the well on March 10, 1894, with the result of an immediate increase in the yield of oil. Specimens of the oil were transparent, of straw colour, with practically no fluorescence. The specific gravity is 0·816 at 60° Fahr., and the flashing-point is 175° Fahr. The report deals at length with the geological features of the district.

The Oil Shale Industry in France.—A full account of the oil shale industry in France, by G. Chesneau,† has recently been published in English. It is practically identical with the French paper by the same author.‡

Petroleum Industry of Galicia.—D. Bellet§ traces the development of the petroleum industry of Galicia from its commencement in 1830. The system of working was then very primitive, and the treatment of the product when extracted was so rudimentary, that it led to great waste of material.

The system obtaining at the present time is described, and the principal works existing in Galicia are enumerated. The Galician raw oil contains 56 per cent. of petroleum, 12 per cent. of benzene, and 1·5 per cent. of paraffin. The Austrian Government has encouraged the industry

* Paper read before the Congress of Chemists at Chicago, *Iron and Coal Trades Review*, vol. xlviii. p. 39.

† *Transactions of the Federated Institution of Mining Engineers*, vol. vii. pp. 180-205.

‡ *Journal of the Iron and Steel Institute*, 1893, No. II. p. 378.

§ *Moniteur Industriel*, 9th January 1894; *Board of Trade Journal*, vol. xvi. pp. 156-158.

by all means in its power, and the development has been extraordinarily rapid.

J. de Clercy * describes the ozokerite industry in Galicia. In the neighbourhood of Boryslaw there are about thirty workings and six factories for the purification of the wax. The outturn of these workings is about 10,000 tons. The ozokerite is found in schistose rocks, below strata of clay and sand. It is worked by the native, and by the so-called French methods. In the former, single pits are sunk, and galleries are driven out as far as possible, with but little timbering. All the stuff is raised by windlasses; and a small amount of water causes the abandonment of the pit. In the latter, better machinery is employed.

Petroleum in India.—In a lecture delivered at the Imperial Institute, R. D. Oldham † described some of the known petroleum fields of India. The operations that had been carried on in the provinces of Khatan, Rohri, Baluchistan, Mogalkol, and North-West Punjab, had, for the most part, been unsuccessful, and he had come to the conclusion that but a very limited field of oil was to be obtained on the western frontier of India. In the east the failure of the operations in Upper Assam, where the oil springs extended some 100 miles, was due, he thought, to want of skill on the part of artificers employed, and a faulty selection of the sites for boring. The workings which were being carried on in the neighbourhood of the Digboi and Bapung were most promising, and he was hopeful of an abundant yield from them. The time was yet to come when the coal and petroleum fields of Upper Assam, which were unsurpassed both for quality and quantity in the Indian Empire, would be opened and developed. Petroleum was known to exist on the southern margin of the Khasi and Garo Hills, but the promise was not sufficient to justify the heavy expenditure that would be necessary. The only productive oil-field of the empire was in the newly-acquired province of Upper Burmah.

Sumatra Petroleum.—A report from the Acting Colonial Secretary of Singapore on the petroleum trade of that colony indicates the growing importance of Sumatra petroleum. The quality of the oil is good, and the proximity of the oil-field to the consuming market makes the expense of transport trifling, and probably admits of sales at prices with which America and Batoum cannot compete.

* *Le Génie Civil*, vol. xxiv. pp. 106-107.

† *Journal of the Society of Arts*, vol. xlii. pp. 145-156, with map.

Petroleum in Persia.—According to A. F. Stahl,* petroleum is known at numerous localities in Persia, but the occurrences have hitherto been but little investigated. Borings at Daleki have not proved successful; but the oil wells of Kutweis and Ahwez have long yielded petroleum of good quality, which is extracted by the natives in a primitive manner. Oil of similar quality has recently been discovered near Schiraz, and the author has found interesting and promising occurrences near Semnan, and in the mountains to the north of that town. In one case a 20-foot shaft sunk in blue marl yielded 40 to 50 gallons of oil daily. The petroleum was of a dark brown colour, and had a specific gravity of 0·911. It is evident that Persia is rich in petroleum, and the author is of opinion that the industry will become an important one.

The Treatment of Crude Petroleum.—Semenoff † observes that the Ragosin distillation apparatus consists of two parts, heated by direct firing. The lower part serves for the distillation of the raw petroleum, and the upper one for the decomposition of the vapours. The raw decomposition-petroleum has usually a higher flashing-point than is possessed by a petroleum of the same specific gravity but produced by a fractional distillation. The higher, however, the specific gravity, the less is the difference between the two kinds of petroleum, and at a certain density no difference at all exists. The boiling-points of the various kinds of decomposition-petroleum are also lower than those of the equivalent distillation products. The lowest boiling-point lies at 100° C., and is that of the product having the specific gravity 0·755. The product having the specific gravity 0·850 has the highest boiling-point, 310° C. A table is given showing the combustion and flashing points of the oil products of the different specific gravities varying from 0·760 to 0·856. When the raw decomposition-petroleum is purified the specific gravity diminishes, but both the flashing-point and the combustion-point rise, and the oil consequently becomes safer to use, and its illuminating power is higher. In the case of the ordinary petroleum the maximum increase in this direction takes place with the oil of the highest specific gravity, but with the decomposition oil the inverse is the case, the highest oils showing the largest rise in the flashing-points, &c. The purified oil shows no dichroism, and has an aromatic smell. The author considers the use of sulphuric acid and soda as inadvisable in the purification of the decomposition-petroleum.

* *Chemiker Zeitung*, vol. xvii. pp. 1409-1410.

† *Zap. imp. russk. techn. obozr.*, vol. xxvii. part 7-8, p. 1.

A large quantity of these would have to be used to attain a light colour, and the treatment with sulphuric acid actually increases the specific gravity. Thus an oil with the specific gravity 0·815 had one of 0·820 after such treatment. The author proposes instead a distillation method. The use of the decomposition-petroleum, the author points out, possesses many advantages over that of the ordinary oil.

Use of Crude Petroleum as Fuel.—In a report to the Foreign Office, dated January 29, 1894, R. C. Clipperton,* Her Majesty's Consul at Philadelphia, refers to the increasing use of crude petroleum as fuel in the United States. In Detroit crude petroleum is much more extensively used than natural gas, and has displaced coal to a very large extent, chiefly in factories and ironworks. The petroleum supplies come from the Ohio and Illinois oil-fields, being transported by railway in tank-waggon, with a capacity ranging from 80 to 190 barrels. A hydraulic device has been invented which feeds petroleum uniformly into furnaces, and also handles it, thereby saving much material and labour.

Solidification of Petroleum.—The following formula is that used by M. Maestracci,† of the French navy, for obtaining briquettes of petroleum similar to those of coal. With a litre of petroleum, there is mixed 150 grammes of triturated soap, 10 per cent. of resin, and 333 grammes of caustic soda. The mixture is heated, and poured into moulds so as to make the briquettes, which are placed for ten to fifteen minutes in a stove. Trials made at Marseilles with these briquettes have given very satisfactory results.

The Carriage of Oil in Bulk.—E. H. Craggs‡ discusses the structure of vessels constructed for the over-sea bulk oil trade. The first bulk oil steamer was a vessel adapted for the purpose, and sailed from Middlesbrough. In 1888 the coffer-dam was introduced for keeping the oil from the engine space. The author treats of the general arrangement of the tank-steamers, referring to the coffer-dams, the bulk-heads, and the disposition of the engine, and also discusses the structural iron-work of the ship.

* *Board of Trade Journal*, vol. xvi. pp. 283-284.

† *Moniteur Officiel du Commerce*, February 8, 1894.

‡ *Proceedings of the Cleveland Institution of Engineers*, 1893-94, pp. 8-37.

V.—NATURAL GAS.

Natural Gas in Canada.—H. P. H. Brumell* gives a detailed description of boring operations undertaken in the province of Ontario up to 1890. The operations show that there is in southern Ontario a possible thickness of Palæozoic rocks of 4200 feet. Oil was discovered in Lambton county, the only oil-producing territory in Ontario, in 1860, and the first flowing-well was struck on February 19, 1862. The question of the origin of the hydrocarbons is gone into by the author, and notes on the distribution of natural gas and petroleum are given. In appendixes are given a specification of the cost of a drilling rig complete at Petrolea, Ontario, the total amounting to 1715 dollars, and a bibliography of Canadian hydrocarbons.

Natural Gas in Italy.—D. Gibertini and A. Piccinini† have analysed a natural gas which issues at Torre, in Parma; it is accompanied by water of alkaline reaction and a small proportion of petroleum. The gas contains about 95 per cent. by volume of marsh-gas, and 0·12 per cent. of carbonic oxide. A gas containing 91 per cent. of marsh-gas issues at Salsomaggiore, and is utilised as a source of heat and light. Full analyses are given.

Natural Gas in the United States.—J. D. Weeks, in the section of the Mineral Resources of the United States, calendar year 1892, dealing with natural gas, not only gives a large number of statistics, but also deals generally with the subject. Commencing with the history, he gives the following dates as those of the probable first applications:—1821, first economic use at Fredonia, New York, for lighting purposes; 1841, first manufacturing use for evaporating brine at Kanawha Valley, West Virginia; first great explosion at the Rousewell, Oil Creek; 1873, first use in iron manufacture near Leechburg, Pennsylvania; 1875, first pipe line of magnitude, the gas being carried seventeen miles to Etna, near Pittsburgh; 1883, beginning of extensive use of gas. The geological horizons on which gas occur are then briefly dealt with, and the controlling factors for its presence are given as a strata of porous rock under impermeable overburden and an anticlinal formation. The pressure is generally ascribed to water, but some Pennsylvania geologists question this theory. A pressure of 800 lbs. per square inch has been observed,

* *Annual Report of the Geological Survey of Canada*, vol. v. Report Q.

† *Gazzetta Chimica Italiana*, vol. xxiii. pp. 559-576.

but it generally ranges from 500 lbs. downwards. Each field, as a rule, has a normal pressure, and this falls off as the field becomes exhausted. This takes place at a variable rate, and has often been measured. In one instance, the fall averaged about 2 lbs. daily during 646 days. The total waste of gas has been incalculable. As an example, the Haymaker Well, No. 1, wasted gas equivalent to 1000 tons of coal daily for five years. To control the supply, the well is just bored as near as possible to the gas layer and then deepened gradually as required. Instead of this, the well may be packed like an oil well, or a valve may be fixed to the top of the casing, which has then to be securely anchored in position. For the conveyance of gas, its high pressure renders it easy to lead it through pipe lines, but when the pressure falls it has been successfully forced through the mains by artificial means. In Kentucky, on one line of 8-inch pipes, thirty miles long, two duplex compressors with 22-inch steam cylinders, 18-inch gas cylinders, and 30-inch stroke, are placed ten miles from the wells. The pressure at the well averages 15 lbs. At the well side of the pump it ranges from 17 lbs. to a vacuum of 3 lbs. The pumps are not only used for urging the gas forward, but are also used to extract the gas from the wells by suction. In some cases a pump will drain other wells within a considerable distance, and even produce a down current in adjacent wells. Water, or oil, above the gas layer may be tubbed out, but if it is below it is not always possible to deal with it.

The author then gives statistics, quoting from the eleventh census report, and giving details for 1891 and 1892 as far as they are available. Owing to the increasing scarcity of the gas, the producers are insisting upon the more extended use of meters, besides raising prices. The meters enable a much better computation of the production to be made. The value of the gas used is given, and from the known quantity of other fuel required for equivalent uses, it is possible to make any number of calculations with regard to the gas. The following table shows approximately the value in millions of dollars of the gas consumed in the years mentioned :—

1885.	1886.	1887.	1888.	1889.	1890.	1891.	1892.
4·85	10·1	15·8	22·6	21·1	18·8	15·5	14·8

The principal producing States are then dealt with separately.

Utilisation of Natural Gas Pipe-Lines.—For the purposes of the water-supply to the Oliver Coke Works near Uniontown, Pennsylvania, use has been made of an abandoned line of pipes formerly employed for

conveying natural gas. This line is about ten miles long, partly of 10-inch and partly of 8-inch pipes, and will supply water for 600 ovens. The method of utilising these pipes is described by G. S. Davison.*

VI.—ARTIFICIAL GAS.

Gas Firing.—A. Blezinger† observes that a system of gas firing always consists of two parts, the gas producers and the combustion chambers. The production of gas again is divisible into two parts, the degasification of the coal, and the gasification of the residue. The author proceeds to consider the question as to what is the best composition for the producer-gas. If very high temperatures are required the gas should contain as much hydrogen and hydrocarbon as possible, with as little nitrogen and carbonic anhydride, while for lower temperatures a mixture of carbonic oxide and nitrogen suffices. The general rule is that the lower the percentage of non-combustible gases contained in the gas made, and the lower the temperature at which it leaves the producer, the more profitable a gas-producing plant is. A table is given showing the variations which have gradually taken place in the composition of the gas. The first column shows the composition of the gas made in the older producers worked simply by draught from the stack; the second, that made in more modern shaft-shaped producers with a forced blast; and the third, that from shaft-shaped producers of the newest types.

	I.	II.	III.
	Per Cent.	Per Cent.	Per Cent.
Carbonic anhydride	7.5	4.0	2.0
Oxygen . . . . .	...	...	0.6
Carbonic oxide	21.5	22.5	28.4
Hydrogen	0.5	6.0	9.0
Olefiant gas	2.5	2.1	2.1

The percentages of combustible gases in the three cases is thus 24.5, 30.6, and 39.4. The deposition of soot has been and is a matter of much moment, and has not yet been prevented. The author gives sections through a producer which, he states, reduces this difficulty to a

* *Proceedings of the Engineers' Society of Western Pennsylvania*, vol. ix. No. 5. pp. 2-6.

† *Stahl und Eisen*, vol. xiii. pp. 462-472. with illustrations.

minimum, and which at the same time yields excellent working results generally. He then proceeds to discuss the use of a forced bottom blast and its production, pointing out that it is cheaper in the long run to provide the producers with their separate boilers. The utilisation of the producer gas is next considered. As regards its combustion this is never in practice perfect. There is never produced a mixture which is simply carbonic anhydride and nitrogen; free oxygen, or carbonic oxide, or both, are always present. Two analyses of the combustion products escaping into the stack, published originally by Bunte, show these to have had the following percentage composition:—

Carbonic Anhydride.	Carbonic Oxide.	Oxygen.	Nitrogen.
14·62	2·07	2·07	80·24
8·24	0·05	10·81	80·81

The first of these products was accompanied by much soot. To effect perfect combustion without using an excess of oxygen is in practice impossible. The best results are obtained by heating to as high a temperature as possible the gas and air before combustion, and ensuring a thorough admixture of the two. This is possible by an arrangement which the author sketches and which he says can be readily attached to any existing furnace. Various kinds of regenerators are also considered. Some of these the author illustrates. He further lays stress upon the necessity for a continuous control of the temperatures and chemical composition of the various burnt and unburnt gases made.

Mixed Producer-Gas.—F. Fischer* describes an examination which he has made of a newly erected plant for the manufacture of mixed gas. Owing to the use of too much steam the gas produced was of bad quality. The author first considers calorimetrically the combustion of carbon by oxygen, by carbonic anhydride, and by steam, and he shows that the degree of utilisation of coal when burnt to mixed gas was to that burnt to ordinary producer-gas as 1·21 : 1. An analysis of the mixed gas referred to is as follows, by volume:—

Carbonic Anhydride.	Carbonic Oxide.	Hydrogen.	Nitrogen.	Total.
8·6	25·8	17·2	48·4	100·0

The producer used in the manufacture of mixed gas at the works the author examined, varied somewhat in form from that customary at other works. It has its greatest sectional area near the point from which

* *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xli. pp. 573–576, 583–584.

the gas is withdrawn. By the use of an iron ring the passage of the coal charged into the circular gas take-off is prevented. The coal used was Welsh anthracite, having the composition—

Carbon.	Hydrogen.	O+N+S.	Ash.	Total.
92.31	3.07	1.52	3.10	100.00

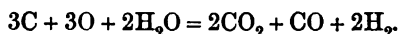
On being coked there resulted—

Fixed Carbon.	Ash.	Volatile Matter.	Moisture.	Total.
87.26	3.01	7.13	2.60	100.00

The average composition of the gas produced was as follows :—

Carbonic Anhydride.	Carbonic Oxide.	Marsh Gas.	Hydrogen.	Nitrogen.
15	9	1	21	54

This appears to correspond to the reaction—



The temperature was not high enough to admit of the direct reaction $C + H_2O = CO + H_2$. One cubic metre of the gas had a calorific power of 1092 calories, and its quality was consequently very poor. The temperature was too low to decompose tarry matter, which collected and clogged the pipes. It may in cases be found more useful to exhaust than to blow in air by the aid of a steam jet. The author proceeds to discuss the injection of carbonic anhydride, and observes that more cannot be used than is shown in the reaction : $5C + 4O + CO_2 = 6CO$.

Siemens made use of combustion products containing carbonic anhydride, but the large quantity of nitrogen that then has to be heated is in practice a very serious disadvantage. If when steam is used the air-steam mixture were subjected to a preliminary heating to a temperature of 500° or 550°, it would be possible to use about double the quantity of steam, and the calorific value of the fuel might rise to about 94 per cent. as compared with the much lower percentages otherwise obtainable, and the gas might have the composition—

Carbonic Oxide.	Hydrogen.	Nitrogen.
39.5	15.8	44.7

with a calorific value of 1612 calories.

If it is possible to preheat the air-steam mixture to as much as 1000°, yet better results are attainable, as the author shows.

The author gives a number of calculations, and shows that the introduction of combustion products into the producer is in every case a mistake. Other points as to the use of air and steam, or both, are also considered, as also is the question of the regeneration of blast-furnace gases.

Gas from Peat.—A recent report by F. T. C. Linton * deals with the manufacture of gas from peat. Most of the water was removed by a preliminary drying, and then the peat was distilled. The results were as follows :—

Locality.	Yield per Ton.		
	Gas. Cubic Feet.	Coke. Lbs.	Tar. Gallons.
Penicuik	2116	378	5½
Leadburn	5404	1372	7
Orkney	9791	812	10½

From six to seven times as much carbonic anhydride as compared with that in crude coal gas would have to be removed.

Gas Producers.—W. E. Koch † gives illustrations of several forms of gas producers, and states that he prefers those with sloping sides. The average assay of Pittsburgh coal shows—

Water.	Volatile Matter.	Fixed Carbon.	Sulphur.	Ash.
1.0	32.5	56.0	2.0	8.5

This should give, per ton of coal, about 130,000 cubic feet of gas of the following composition, by volume :—

Carbonic Oxide.	Hydrocarbons.	Hydrogen.	Carbonic Anhydride.	Nitrogen.
26	2	11	3	58

The caloric value of 1 lb. of coal is 14,000 heat units, and that of the gas made from it in a closed front producer, with steam blast, is 9500 heat units, a loss of 33 per cent. in the producer. The producer is then considered with regard to the action in three zones, the lower or combustion zone, the decomposition and the distillation zones. High temperature in the upper zone breaks up the hydrocarbons, and causes soot to be deposited in the flues, whilst low temperatures drive off the hydrocarbons, which are ultimately decomposed in the chequer work of the regenerators. Probably the hydrocarbons cause more trouble than they are worth. The steam supplied should be dry, in moderate quantities, and at a low pressure. A deep fuel-bed should be used. It is suggested that hydrocarbons carry over sulphur in a form injurious to the charge.

* *Industries and Iron*, vol. xv. p. 755.

† *Proceedings of the Engineers' Society of Western Pennsylvania*, vol. ix., No. 6, pp. 2-14.

The author then considers the present efficiency in the use of gaseous fuel, and shows how enormous the waste is. In heating steel to rolling temperature 1 lb. of coal should heat 60 lbs. of steel, instead of only 12 lbs. Similarly, for raising iron to welding temperature, the figures are 50 lbs. instead of 9 lbs., and for melting 27 lbs. instead of 4 or 5 lbs. More attention should be paid to the reduction of this waste.

In a text-book on gas, oil, and air engines by Bryan Donkin,* recently published, a succinct account is given of the manufacture and properties of various kinds of producer, oil, and other gases. A short historical account is given of producers, and those of Lencauchez and Dowson are more particularly described. The chapter on the chemical composition of gas is by G. H. Huntley, and in this the calorific value is also dealt with. The utilisation of heat in gas, oil, and air engines is treated at length, and carefully compared with that in the ordinary steam-engine. Besides dealing with the general properties of oil, some attention is paid to the question of its direct use as fuel.

The Taylor Gas Producer.—In the discussion† on C. A. Stetefeldt's paper‡ on the consumption of fuel in the Taylor gas producer plants at the Aspen and Marsac Mills, W. H. Blauvelt remarks on the saving that has arisen since gas has replaced wood. He disagrees with the author's observations on unlined pipes, and prefers that they should always be lined, as a proper disposition of draught always permits them to be burned out, a preferable arrangement to hand cleaning. The lining also prevents strains from expansion and contraction, and thereby diminishes repairs.

G. W. Goetz also prefers lined pipes to the spirally welded pipes advocated by the author, and has found the Wellman producer preferable to the Taylor, both on account of cost of working and erection, and of the clinker made by the Indiana and Illinois coal.

The Use of Water-Gas.—Regulations relating to the precautions to be observed in the use of water-gas and of semi-water gas have been issued by the German Ministry of the Interior.§ The gases should be prepared and purified in buildings where there is a free access of air. The charging apertures of the gas producers should have double seats.

* "A Text-Book of Gas, Oil, and Air Engines," London, 1894.

† *Transactions of the American Institute of Mining Engineers* (advance proof).

‡ *Journal of the Iron and Steel Institute*, 1893, No. II. p. 384.

§ *Journal für Gasbeleuchtung und Wasserversorgung*, vol. xxxvi. pp. 31-32.

Care must be taken that the pipes are perfectly gas-tight. Underground pipes must be placed at such a depth that they are not liable to be acted upon by frost. Methods of testing the pipes are given, those advocated consisting of the use of the Muchall controlling apparatus, the addition of mercaptan to the gas for rendering its presence evident by the odour, and the use of palladium paper, which is darkened by the reduction of palladium by carbonic oxide.

VII.—COAL-MINING.

New Method of Boring.—A method is described for boring through rock, which is intended to replace the diamond drill. In this method steel shot are poured inside the drill pipe into a ring or channel made in the rock by a few revolutions of the pipe. The pipe bears heavily on the shot, and when revolved the rock is cut by the revolving shot, and the channel cut deeper. A test-boring, 8 inches in diameter and 390 feet in depth, is stated to have been already put down.*

Boring for Coal in Victoria.—At Korumburra, Victoria, a bore-hole put down to a depth of 691 feet, passed through 1 foot of coal at a depth of 351 feet, 2 feet 5 inches of coal at 356 feet, a 6-inch seam at 432 feet, one of 8 inches at 436 feet, another of 21 inches at 438 feet, and the bore-hole, which is still being continued, also passed through a 10-inch seam.†

The Sinking and Equipment of Shafts.—An exhaustive series of articles on shaft-sinking has been published.‡ The subjects discussed are as follows: Description of an ordinary sinking, head-gear, kibbles, landing arrangements, inclined or diagonal shafts, sinking of slopes or slants, sinking guides, walling of shafts, walling materials, and concrete and cement walling.

Shaft Sinking through Quicksand.—C. Hilgenstock§ gives some particulars of the method of sinking two shafts through 15 metres (49 feet) of quicksand at Jemappes, Belgium, with the aid of compressed air. The tubbing consists of ten rings, of which six rings were first built up on the surface, and the remaining four were added when the

* *Australian Mining Standard*, vol. ix. p. 507.

† *Ibid.*, p. 464.

‡ *Engineering*, vol. lvii. pp. 153-155, 217-218, 279-281, 405-406, 533-535, with 76 illustrations.

§ *Colliery Guardian*, vol. lxvi. p. 1103.

first set had sunk level with the surface. The lower part of the tubbing was closed by a floor attached to the middle ring, and strengthened by brackets, and this carried a central chimney, 1·5 metre (5 feet) in diameter, which formed the air lock. In the first instance, this was 1·9 metre (6½ feet) high, but it was lengthened when the four rings of tubbing were added, the pressure in the lower part of the tubbing being maintained by the aid of a special pipe passing through the floor above mentioned. The chimney was surmounted by a winch in the air-tight casing for hoisting the spoil, which was discharged through a small lock projecting from the side. The winch was driven through clutch gear from a continuously running engine outside. Ladders were placed inside the chimney for the men to ascend and descend.

A. Lupton * describes the sinking of a shaft through 50 to 70 feet of quicksand, which was done some years ago in Flintshire. The work was carried on with the aid of diving dresses, and also with a diving-bell for part of the time.

The Freezing Process of Shaft Sinking.—Gobert † describes the plant used for the production of cold in his process of sinking shafts. This consists of an ammonia compression machine. The liquid ammonia falls down through waved or serpentine tubes placed inside larger tubes sunk in the quicksand to be frozen. As it escapes from holes in the inner tubes it evaporates and produces the cold, the gaseous ammonia being drawn away from the outer pipes by the compression pumps. Special forms of joints in these pipes are used, consisting of internal sleeves screwed into place with lead or other washers. The tubes are sunk in two concentric circles, and are connected at the beginning of the operation to a common centre. For widening a shaft a row of tubes is sunk around it, and after the ground is frozen it is worked out from below upwards in lifts of 1½ to 2 yards. As each lift is finished, it is proposed to put in the new tubbing and to replace the old tubbing, fitting in the space between with bags of wet sand. On reaching the surface, the old tubbing and the fitting are removed from above.

Sinking Shafts at the Sydney Mines.—R. H. Brown ‡ describes the tubbing and the sinking of the shafts at the Sydney mines, Cape

* Paper read before the Midland Branch of the National Association of Colliery Managers, March 17, 1894.

† *Comptes Rendus Mensuels de la Société de l'Industrie Minérale*, 1894, pp. 34–38, with two plates.

‡ *Transactions of the Mining Society of Nova Scotia*, vol. ii. pp. 158–166, with three plates.

Breton. Two pits are sunk to the coal, 13 and 11 feet in diameter, and 682 and 709 feet in depth respectively. There is also an auxiliary pumping pit 389 feet in depth. The sinking of these shafts was commenced in 1867, and a feeder of water was met at a depth of 200 feet. This was dealt with by a set of 8-inch pumps, but at a depth of 267 feet salt water came in direct from the sea through fissured sandstone. The upper feeder was then cut off by cast iron tubbing. The Cornish pumping engine, with a 62-inch cylinder and 9 feet stroke, had been erected, and a set of sinking pumps, 20 inches in diameter, was installed. Some 650 gallons of water per minute was raised day and night until solid sandstone was reached at a depth of 323 feet. A wedging crib was then put in, and the shaft tubbed up to the previous tubbing, after which the two shafts were sunk dry. The winding shaft was then continued, the water being dealt with by a bore-hole sunk to the other shaft. The tubbing was cast in segments 24 inches deep, and was put in by lifts, the height of which depended on the soundness of the strata for wedging cribs. Each segment had a 4-inch flange, and a 4-inch brass valve was placed behind each crib to deal with the air. Details of the number of cribs and of the amount of tubbing are given, a total depth of 1158½ feet being tubbed. Pockets were cast on the segments to receive the buntons.

The Heinrich Shaft of the Mönnich Colliery, Karwin.—J. Kohout* observes that in 1887 an old shaft belonging to this colliery caved in. This was afterwards cleared out again, though with considerable trouble, and walled for its full depth. It was thought advisable, however, to construct another shaft, and this was put down at a distance of 193 feet from the original shaft. This winding shaft, and the various buildings and appliances connected with it, are described and illustrated.

New Winding Engines.—Graillet† describes the winding engine Eugenie No. 2, at the Blanzey Collieries, which was erected in 1890. This engine has Wheelock valves and a cylindro-conical drum. It is designed to raise up to 1800 tubs per nine hours, from a depth of about 765 yards, but at present is not working up to its full capacity. Full dimensions of the main parts are given, from which the following

* *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xli. pp. 589–591, three plates of illustrations.

† *Bulletin de la Société de l'Industrie Minérale*, vol. vii. pp. 334–341, with plate. 1894.—i.

are selected :—Diameter of cylinders, 41·3 inches ; stroke, 62·9 inches ; diameter of drum, $32\frac{3}{4}$ to 34 feet ; breadth of conical part, $70\frac{3}{4}$ inches, of cylindrical part, $15\frac{3}{4}$ inches ; number of spirals on conical part, 22. Particulars of the brake are also given, and calculations of the power are appended.

New winding plant has been installed at the Benjamin Shaft of the Ferdinand Mine at Kattowitz, in Upper Silesia, capable of raising 2000 tons in 10 hours from a depth of 300 yards. The cages employed have four decks, and carry eight waggons.*

Winding Ropes in the Dortmund District.—From 1872 to 1892 the number of winding ropes employed in the Dortmund district was as follows :†—

Flat ropes, cast steel	545
„ iron	147
„ aloë	95
„ hemp	8
Round ropes, cast steel	2615
„ iron	877
Total winding ropes	4287

Of this total, 238, or 5·55 per cent., suddenly broke during the 21 years (1872–92), the proportion of accidents to each variety of rope being as follows :—

	No.	Per Cent.
Flat ropes, cast steel	39	7·17
„ iron	19	12·93
„ aloë	7	7·37
„ hemp . . . . .	...	...
Round ropes, cast steel	68	2·60
„ iron	105	11·97

The number of fractures has decreased fairly regularly since 1872, the annual returns being as follows for the years specified :—

	No. of Ropes.	Accidents.	Per Cent.
1872	114	22	19·30
1880	170	8	4·71
1890	246	5	2·03
1891	284	12	4·23
1892	264	5	1·89

* *Zeitschrift des Oberschlesischen Berg- und Hüttenmännischen Vereines ; Glückauf*, vol. xxx. pp. 72–73.

† *Glückauf*, vol. xxx. p. 54.

The Use of Locked-Wire Ropes for Winding.—At various collieries of the Dortmund coalfield locked-wire ropes are employed for winding purposes,* and in the course of six months' use have given satisfaction. The rope used at the Heinrich Gustav Colliery has a breaking strength of 66·85 tons, the rope having a diameter of 1·2 inch. It consists of a wire core of 36 round wires, surrounded by three outer layers of shaped wires, these wires being respectively 25, 32, and 35 in number in the different circles, their diameter also increasing from the inner to the outer layer. The total bearing section of the rope is about 80 per cent. of the apparent section. A rope made of ordinary wire would consist of about 144 wires, and have a diameter of 1·6 inch, if the breaking strength was to be the same as that of the above locked-wire rope. This is the chief advantage of this latter form of rope. Perhaps for ordinary winding purposes the locking of the wires is rather a disadvantage than a gain. It does not render the construction of the rope impervious to water, as the spaces between the wires must be constantly opening and closing to a greater or lesser degree, and moisture can get to the centre of the rope. Another disadvantage consists in the fact that any fracture of the inner wires cannot possibly be observed from the outside of the rope. Other disadvantages are also pointed out.

Fences for Winding-Shafts.—The arrangements in use for closing shaft landings at several collieries are described by Ichon† under three headings:—Those in which the closing of the fence without being automatic depends on the working of the stops or of the signals, which can only be worked to liberate the cage after the fence has been closed; those in which the closing is automatic and the opening done by hand; those in which both opening and closing are automatic. Examples of these different forms of doors are described and illustrated.

Safety-Catches for Mining Cages.—O. Vogel‡ illustrates a safety-catch devised by Messrs. Haniel and Lueg, which is stated to be perfect in its action, unfailing if the rope breaks, but not coming into action unless this takes place. It consists of a system of bolts and of plates held in position by a piece of copper pipe, which is cut through if the rope breaks, enabling the catch to come into action.

* *Zeitschrift für das Berg-, Hütten- und Salinenwesen im preussischen Staate*, vol. xli. p. 199.

† *Comptes Rendus de la Société de l'Industrie Minérale; Colliery Guardian*, vol. lxi. p. 1152.

‡ *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xli. p. 592, two illustrations.

R. Khun * observes that experiments have been made at the Hanover I. Colliery, near Hörde, in Westphalia, with a cage to which a Münzner safety-catch had been connected. This catch stops the cage by throwing knife-shaped arms into the wooden guides in the shaft. The total weight of the cage and of the rope hanging from it was 7.95 tons, and the experiments were made to ascertain the shock to which the men in the cage would be subjected if the rope were to break and the cage be caught by this catch. It has been shown that a man standing upright cannot fall more than a foot without danger. Care was taken, in designing this catch, that the shock to which the men would be subjected should not be greater than that resulting from a free fall of the above height. This involves specially-shaped catching arms for cages of different weights, and for the different kinds of wood used in making the guides. The experiments which were made showed that the shock would be far less than that of the above permissible limit. Neither the cage nor the catch suffered any damage, nor did the woodwork pierced by the knives of the catch show more damage than that resulting from the simple cutting action of the blades of the safety-catch.

Signalling from a Moving Cage.—At the König Colliery, in the Neunkirchen district, an arrangement is attached to the cage by which a whistle can be sounded that is audible at a distance of some 1100 feet. It consists of a cylinder filled with air at a pressure of twenty atmospheres, provided with a whistle controlled by a valve connected with the inside of the cage. The pressure cylinder is 6.3 inches wide and two feet in length, and one charge of air suffices for 150 signals. †

The Thomas Collieries, Tennessee.—T. Calhoun ‡ describes the gravity arrangements for dealing with coal and water at the Thomas Mines, Whitwell, Tennessee. The Sewanee seam, which is worked, is 3 feet in thickness, nearly horizontal, and crops out for over fifty miles along the face of the mountains. Mules are used for underground haulage, and a self-acting incline is used for lowering the coal and raising the empty trucks. The tubs hold 1 ton, and run on a gauge of 26 inches. They are emptied by tips, into trucks holding 5½ tons

* *Zeitschrift des Vereines deutscher Ingenieure*, vol. xxxviii. p. 296, one illustration.

† *Zeitschrift für das Berg-, Hütten- und Salinenwesen im preussischen Staate*, vol. xli. p. 206.

‡ Paper read before the Engineering Association of the South, February 8, 1894; *Engineering News* (New York), vol. xxxi. pp. 163-164.

each, on a 4-foot gauge. The incline has three rails, with four rails at the passing places. It is 4700 feet long, with a rise of 1035 feet. The speed of the drum at the head of the incline is controlled by a hand-brake, and also by fans, which are geared up so as to limit the speed to 1200 feet per minute. Ten trips per hour are made with two trucks, which are made so that their tops are level on the incline. At the foot the trucks are uncoupled, and are run by gravity for a distance of 500 feet to the screens, which are arranged so that the coal passes through all of them by gravity, and is loaded into the railway trucks. Siphons are used for draining the mines.

Endless Rope Haulage.—W. J. E. Carr * describes the endless rope haulage by stationary electric motors at the Leavenworth Coal Company's mine, Kansas. There are two lines, each with 22-inch gauge. On the line most recently laid down, the length is 2200 feet, and very crooked. A 40 horse-power motor is used, running at 700 revolutions. The driving drum runs at 12 revolutions, mortised wood reduction gear being used. With six Carr's cable grips, 400 tons per day are hauled, with an expenditure of 20 horse-power. The plant is fully illustrated.

W. J. E. Carr † describes a means of using endless rope haulage on a single line of rails. The ropes are run 6 inches apart between the rails, and are carried on rollers 25 feet apart. On curves, sheaves with vertical axes are used, and the ropes are placed rather farther apart. On slight curves, guide plates are used to direct the grips. The tubs are made up into trains, and are connected to the rope by a grip truck. Passing places are provided, and short lengths of double lines at the ends. The grip has a swinging as well as a lateral motion, to enable it to follow the rope.

F. Stolz ‡ gives some practical results of mechanical haulage with endless rope, in reply to the objections raised by P. Jorissen. §

A chain-haulage plant was erected at the Gutehoffnungshütte, near Sterkrade, in 1886. The first fracture of a link occurred in 1892. The total length of the chain is over 14,200 feet, and it weighs about 16 lbs. per yard. Before the first fracture occurred it had been at work for 19,228 hours, and during this period had hauled 1,898,416 tons of coal and other material. Between the moment when work was first started, and the period of the first fracture, the chain had stretched 6 per cent.

* *Journal of the Illinois Mining Institute*, vol. i. pp. 262-265, with plates.

† *Ibid.*, pp. 341-346, with plates.

‡ *Glückauf*, vol. xxx. pp. 1-5.

§ *Ibid.*, vol. xxix., Nos. 82 and 83.

An endless rope is in use near Konradsthal, in Silesia, in the main level of the David Mine, and although it has been in constant use for five years, is still in perfect condition. In another case to which reference is made, an endless rope used in a similar way only lasted three months before fracturing, and another case is also mentioned in which the wear of the rope was extreme. This was due to very careless manipulation.*

Haulage at East Howle Colliery.—Some notes on underground haulage at the East Howle Colliery are given by E. Graham.† Hand putting and pony haulage are first dealt with in some detail, and then the results of some experiments to find the friction of tubs are given. These experiments were conducted in a similar manner to those of the North of England Institute Tail Rope Committee, and gave an average co-efficient of $\frac{1}{107}$ and $\frac{1}{85}$ for full and empty tubs respectively. There are three self-acting inclines, and another incline is similarly laid out, but ponies are used, one being attached to the empties and another to the full tubs, the two sets being connected by a rope. Both start at the same time, so that each does half the work. Main and tail rope haulage is employed in two out of the three seams. After describing this generally, the author refers to some of the details, such as the crossings, ropes, and rollers. Wood and steel rollers are used, the former being preferable. The duration of the ropes is referred to, and also the method of applying the tail rope to pumping. Spring wheel-greasers are used. Some attention is given to the costs of various items.

Electric Haulage at the Mines of the Brock Coal Company, Pennsylvania.—The mines of the Brock Coal Company consist of five drift openings in a hillside near Brockwayville, Pennsylvania. The coal seam averages 31 inches in thickness. The outside tramway connecting the four drifts with the railway is about a mile in length, and electric haulage is employed. Two electric locomotives are used, drawings and descriptions of which have been published.‡ Compared with the mule haulage formerly employed, great economy has been effected. The average cost of producing coal, before the introduction of the electric plant, was 41·839 pence per ton, whilst the present cost is 37·288 pence per ton.

* *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xli. p. 587.

† *Journal of the British Society of Mining Students*, vol. xvi. pp. 48-68, with illustrations.

‡ *Engineering and Mining Journal*, vol. lvii. pp. 56-57; *Electrical World*, December 16.

Electric Haulage at Dumbreck Colliery.—J. T. Forgie* describes the electric plant at Dumbreck Colliery, Kilsyth. Two seams are worked through two pits, the total output being up to 950 tons daily. Self-acting haulage was used until the workings became too extensive, when sufficient power was not developed. The water also increased. After consideration of the various methods of transmitting power, electricity was decided upon. A four-pole compound dynamo, giving 600 volts and 62 ampères at 400 revolutions, was put up, but the voltage used at present does not exceed 400. The main conductor is 1000 feet long, and is an armoured concentric one weighing 11 lbs. per fathom. A two-pole shunt wound motor, capable of developing 20 horsepower, is used to drive the rope at $1\frac{1}{2}$ mile per hour in one road, and as this proved satisfactory, similar plant was used for the other haulage roads. Concentric cables of smaller size are used to convey the current to the different haulage motors, and also to three pump motors, the total length of the conductors being 14,500 feet. The cost of the plant, with particulars of its various parts and of its working, are given, but no detailed efficiency tests have been made. The dangers of sparking are then considered in some detail.

A Wire Ropeway in Japan.—Professor J. Milne† gives some particulars of a wire ropeway on the Hallidie system, with a single endless supporting and hauling rope, which is used near the Ashio Mines in Japan. Its length is 4110 yards, with seventeen supports. The longest spans are about 560, 460, and 380 yards. The buckets carry 200 lbs., and are spaced 109 yards apart. The speed is 55 yards per minute, and the rope uses about 8 or 9 horse-power. Roe and Bedlington's grip saddles are used, and balanced sheaves.

Electricity in Mining.—F. O. Blackwell‡ enumerates the advantages arising from the use of electricity for mining purposes, especially mentioning those derived from its use for the transmission of power to a distance. Generators are now obtainable of any size and power. In the United States some three hundred companies employed in mining or kindred operations employ electricity. Usually the voltage is 220 or 500 volts, but a few employ 1000 volts or more. At present

* *Transactions of the Federated Institution of Mining Engineers*, vol. vii. pp. 121-134, with one plate.

† *The Miners' Handbook*, London, 1893.

‡ *Transactions of the American Institute of Mining Engineers*, Chicago Meeting, 1893 (advance proof).

direct currents beyond 1500 volts cannot easily be generated, and the economical limit of distance for the transmission of this pressure is about four miles. With alternating currents, transformers are employed to obtain any suitable voltage. Motors have been designed to meet all special requirements of mining work. The most successful application of electricity has been to haulage, it being used in about thirty mines. One great advantage of electric haulage is that the locomotive can be built to suit any size of road. Electric hoists are in extensive use, and they avoid the reciprocating parts incidental to steam or air engines. They give an efficiency of 50 to 60 per cent. between the power taken and the work done. Large pumping plants are in operation. The best method of regulation is to make the fields of the motor of such strength as to give the minimum speed desired, so that by decreasing the current in them, the speed may be increased up to the maximum output. Where many pumps of nearly the same size are in operation, a convenient method of regulation is to throw the pumps into multiple series combinations with each other. Centrifugal pumps may be used, but their efficiency is low. The same statements are applicable to electric air compressors, which may be placed near the rock drills. With care in designing the solenoids, percussive rock drills can be made a success, and diamond and other rotary drills driven by electricity have found considerable favour. Electric coal cutting machinery is now largely in use in bituminous coal mines. Most of these have a rotary bar cutter, but percussive machines are advantageously employed in hard or pyritiferous seams. Electrically driven fans are useful in the mine, and electric lighting is, of course, invaluable.

In another paper treating of the various applications of electricity to mining, F. O. Blackwell * gives illustrations of the power transmission line near Ouray, Colorado, an 80 horse-power electric locomotive with 30 trucks at Rock Springs, Wyoming, 150 horse-power double drum electric hoist, centrifugal pump with direct connected motor, an electric ventilating set, a 50 horse-power two-motor mining locomotive, an electric sinking pump, an electric percussion drill, and a rotary diamond drill worked electrically.

Faiveley † deals with the application of polyphase currents for use in mines. Ordinary alternate current motors are difficult to start, as they have several dead points, but this is overcome in motors with a rotating magnetic field. The principle of these is shortly described, and reference

* *Cassier's Magazine*, vol. v. pp. 249-258.

† *Bulletin de la Société de l'Industrie Minérale*, vol vii. pp. 486-498.

is made to the Lauffen-Heilbronn and the Niagara installations. As an example of the application of alternating biphasic currents, the plant erected by Schneider & Co. at the Decize Mines is described. In this plant several Ser fans at isolated points are driven from a central generating station by six motors of 15 to 30 horse-power. In addition, 15 arc lamps are supplied with current, and also some incandescent lamps. The arrangement of the generating dynamos, switch-boards, and motors are described. One advantage of these rotating field-motors is that there are no brushes, and consequently no sparking.

R. H. Wynne* deals generally with the application of mechanical arrangements in underground operations. The subject is treated under the heads of horse-power, steam, compressed air, electricity, and the combustion of petroleum, the various advantages being shortly considered.

C. Schencke† describes, with the aid of five plates, the plant for electric power transmission and lighting at the Carl G. Falck Colliery at Bockwa, near Zwickau.

An attempt is about to be made to transmit power electrically by means of high-tension alternating currents to all parts of the kingdom of Saxony from one central generating station. In the first instance it is intended to transmit power to 158 places, using as a generating centre the Haenichen Collieries, to the south of Dresden.‡

E. A. Sperry§ discusses the relative merits of electric and compressed air transmission of power in mines, and gives a short bibliography of recent literature on the latter system.

Electric Conductors in Mines.—J. Libert|| discusses the use of electric conductors in mines, mentioning the safety-cables devised by Atkinson and by Charleton, and also describing another form invented by Noblet at Seraing. In this cable there is a small auxiliary conductor, which is arranged so that it breaks before the main conductors are broken. This is done by introducing sliding couplings into the cable at intervals. When the small conductor breaks, it causes the main circuit to be broken at the generator or in some safe position before the couplings are entirely parted. The chief conditions for wiring in fiery mines are given.

The best arrangements for the electric conductors for power or lighting

* *Transactions of the Federated Institution of Mining Engineers*, vol. vi. pp. 563-571.

† *Jahrbuch für das Berg- und Hüttenwesen im Königreiche Sachsen*, 1893, pp. 93-107.

‡ *Stahl und Eisen*, vol. xiii. p. 1106.

§ *Journal of the Illinois Mining Institute*, vol. i. pp. 209-219.

|| *Annales des Travaux Publics de Belgique*, through the *Colliery Guardian*, vol. lxvii. pp. 157-158.

purposes in mines is also discussed by A. W. Bennett.* Competent men should be employed for laying the wires and cables, which should be covered with good and lasting insulating material. The best substance for this purpose is india-rubber and coated tape. The conductors should be tested for insulation. Wood-casing is unsuitable for underground work, iron pipes through which the conductors can be drawn being more suitable than any other method. The pipes should be waterproofed with white lead, and the joints in the wire made with rosin, and insulated. Lead covering, on the whole, is unsuitable. Brief mention is also made of accumulators.

Compressed Air at the Blanzv Collieries.—Very full particulars have recently been given, by several authors, of the compressed air plant at the collieries at Blanzv. Matthe† describes the apparatus used underground in general terms; and the drills are described in particular by J. Druge.‡ The air compressors are dealt with by De Boisset,§ and the results of their efficiency by Lauras.|| The construction of compressed air machinery at Le Creusot, and its application and efficiency, is described by P. Burdy.¶

Electric Power for Rock Drills at Ischl.—Drawings of the arrangements of rock drills in use at the mines at Ischl, in the Tyrol, worked by the aid of electrically transmitted force, are published by Schedl,** who also describes the results which have accompanied their use in practice. The installation is by the firm of Siemens & Halske, of Berlin, the generating dynamo employed yielding a current of 220 volts and 16 amperes. The power is transmitted direct, the high-pressure turbine used making 100 revolutions per minute to the 1650 revolutions of the dynamo driven by it. Copper wires of half an inch diameter, coated with an asphalt preparation, are employed as the conductors. The wires are carried by porcelain insulators, the arrangement adopted being such that the mine-working is not interfered with in any way. The motor in use is of 1 horse-power capacity, as compared with the 5 horse-power of the primary dynamo. The arrangements for the transmission

* *Transactions of the Federated Institution of Mining Engineers*, vol. vi. pp. 366-371.

† *Bulletin de la Société de l'Industrie Minière*, vol. vii. pp. 343-385.

‡ *Ibid.*, pp. 387-394, with plate.

§ *Ibid.*, pp. 395-410.

|| *Ibid.*, pp. 411-418.

¶ *Ibid.*, pp. 419-463, with six plates.

** *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlii. pp. 155-159, six illustrations.

of the power from the motor to the drills are then dealt with, and the Siemens & Halske revolving drills employed are also described, while the results achieved in practice are shown in tabular form. The diminution in the working costs of the mine which has accompanied the use of the plant is stated to be likely to be considerable.

New Explosives.—A. C. Kayll* gives a list of mining explosives, with their definitions, as authorised from time to time under the Explosives Act of 1875.

Reports have been published of satisfactory trials of the new explosives—*westphalite* at the Zwickau collieries,† and *australite* at the mines in the Broken Hill district of Australia.‡

Blasting in Collieries.—Some notes on blasting in coal mines, by H. Bigg-Wither,§ deal with the various kinds of explosives used in this and other countries, and also with the means for firing the shots. Especial attention is paid to roburite.

A new method of tamping and ramming bore-holes is described by H. Johnson.|| For tamping, cylinders of compressed clay are used. These are made from suitable material in a small hand-press, and are broken up in the bore-hole by the rammer. A central passage is made through these clay cylinders, and also through the head of the rammer, for the reception of the fuse. The inner end of the bore-hole is also preferably made of smaller diameter when a water cartridge is used, and this is protected from injury during tamping by a disc which rests against the shoulder formed by the beginning of the smaller part of the hole. This disc is also centrally perforated for the fuse to pass.

Methods of Working Coal at Blanzy.—Matthet¶ gives a general review of the method of working the thick seams at Blanzy, and mentions the several styles that have been abandoned. The first of these was pillar work before 1836, the pillars being lost. Several methods, in which stowing was used, have been discarded since 1860, nearly all using some arrangement of taking out the coal in lifts. At the present

* *Transactions of the Federated Institution of Mining Engineers*, vol. vi. pp. 346-364.

† *Glückauf*, 1893, No. 97.

‡ *Australian Mining Standard*, vol. ix. p. 464.

§ *Transactions of the Federated Institution of Mining Engineers*, vol. vi. pp. 538-544.

|| *Ibid.*, pp. 550-553, with plate.

¶ *Bulletin de la Société de l'Industrie Minérale*, vol. vii. pp. 343-385, with plate.

time, the actual work of winning the coal and stowing the goaf goes on simultaneously with a continuous circulation of the tubs which remove coal and bring back the packing material. Compressed air is used throughout. The importance of this system is dealt with at some length, and the economy resulting from the diminution of plant and labour required is very large. Although the method of horizontal lifts, working upwards over the stowing, is still dominant in these mines, yet the system of inclined lifts is steadily being introduced, and will in time entirely replace it. The arrangements for circulating the tubs and getting the stuff for packing is then dealt with and illustrated.

Compressed air is used throughout the mines for driving nearly all the machinery, such as the hoists or winches, the portable fans, pumps, and the drilling machines. Particulars of these are given in some detail. Amongst other points, mention is made of the latest modifications of the drills, by which a jet of water is injected in the hole at the end of the stroke. Coal cutting machinery has been experimented with, but owing to the lack of sufficient compressed air, nothing much has recently been done. A series of tables are given, dealing with the principal factors mentioned above.

The construction of the drill mentioned above is fully described and illustrated by J. Druge.* The drill in its main features is that of Dubois and François. To lead the water to the point of the bit, a passage is formed through the piston rod and bit, which are connected by a special coupling. A hollow tail rod on the piston works through a stuffing-box into a chamber to which water under pressure is supplied.

Working Coal in the Rosic-Oslavan Coalfield.—R. Helm-hacker† describes in detail the modes of working employed in the collieries between Rosic and Oslavan, in Moravia. The coal is deposited on gneiss, and is overlain by Permian red sandstone. There are seven coal seams, only three of which are worth working. With the aid of nine illustrations, the author describes the variations of the pillar-and-stall method, with and without stowing, in vogue.

Methods of Working Coal in Illinois.—Q. Clarke ‡ describes the modern method of opening long wall in the Wilmington coalfield, with a sketch of the system. The roads are generally laid off at 45°, and the

* *Bulletin de la Société de l'Industrie Minière*, vol. vii. pp. 387-393.

† *Glückauf*, vol. xxx. pp. 19-20, 38-39, 52-53.

‡ *Journal of the Illinois Mining Institute*, vol. i. pp. 320-323.

advancing method of working is used. In one instance, with a shaft 93 feet deep and a regular seam 3 feet in thickness, the narrow work round the shaft pillar was completed in October, and by June following the output was 1038 tons daily. The life of the mine was 766 working days, during which time 688,619 tons of lump coal were mined and delivered to market.

Stockett* describes, with a sketch, the method of working at the Mount Olive Mines, Illinois. The seam is 8 to 10 feet in thickness, with a fire-clay floor and a good limestone roof. Stalls are driven the full width of 60 feet, leaving pillars of 60 feet between them, and a stump pillar 30 feet wide at the entrance of each stall. The coal is undercut by machinery and blasted down. Rails are laid down the sides of the stall up to the face. Parts of the pillars are removed, on returning, by cross-cuts between the stalls 30 feet wide. Other methods are also discussed, especially long wall deep workings.

J. Freer† describes, with sketches, several methods of working adopted in Illinois, with special reference to the question of creep. The first of these is near Lincoln, in a seam $5\frac{1}{4}$ feet in thickness, overlain by slate and then limestone, and having a fireclay floor. Parallel entries are driven 8 feet wide and 21 feet apart. Stalls are driven off one entry only when working outwards, and from the other when returning. The stalls are 30 feet wide, leaving 6-foot pillars. In a similar instance a sort of panel system is adopted. The parallel main roads are 800 feet apart, and roads are driven from these to meet each other every 160 yards. From these the stalls are worked out. A third system is somewhat similar to the first described, but more coal is left between the stalls and the roads, and the stalls and pillars are 24 and 9 feet broad respectively. The depth in the last two cases is 267 and 194 feet. Since these systems have been adopted there has been no trouble with creep.

J. G. Massie‡ describes several methods of placing bore-holes in blasting solid coal to obviate the necessity of shearing or undercutting. The first shot is put in to free an end to work to, and the succeeding shots are then placed so as to keep the face in a stepped form. The disposition of the holes best adapted for different kinds of coal and varying thicknesses of seam are illustrated as carried out in some of the Illinois collieries, where no cutting at all is employed. This method of mining does not appear to be more wasteful than others, in fact it sometimes gives increased economy.

* *Journal of the Illinois Mining Institute*, vol. i. pp. 234-236.

† *Ibid.*, pp. 238-243.

‡ *Ibid.*, pp. 248-252, with plates.

Coal Cutting Machinery.—T. H. Wordsworth * describes the use of a coal cutting machine of the Gillott & Copley type in the Middleton main or silkstone seam at Altofts, at a depth of 960 feet. The seam is worked long wall with pack gates, the line of face being half end and bord in the lower level; on the higher side of the fault the line of the face is plumb end and 1710 feet long. The good coal is 3 feet 10 inches in thickness, and there is 10 inches of inferior coal at the bottom. The machine cut was first made 3 to $3\frac{1}{2}$ feet deep and $3\frac{1}{2}$ inches high, but subsequently the depth and height were increased to 4 to $4\frac{1}{2}$ feet and $4\frac{1}{2}$ inches, as then the machine cuts better, and the coal comes down more easily. The machine has a cutter disc which is mounted so as to be detachable for transport, and it hauls itself forward. The road for the machine consists of three pairs of flat-bottomed rails, 15 feet long and weighing 28 lbs. per yard, laid on special sleepers. The machine is slightly tilted to prevent the cutter wheel dragging. It is worked by two men who set timber, lay the road, clear out débris, and put in sprags. The average length cut, including removal of the machine and taking off pipes, is 135 feet in eight hours. For transport to another working, the machine and cutter wheel are disconnected and loaded on to separate trolleys. A machine with a cutting wheel 6 feet 1 inch in diameter is now being put to work to increase the depth of cut. Coal is got down by wedging and blasting. Compressed air is used for driving.

Some tests have been made at the Lidgett Colliery, near Barnsley, with the Clarke coal cutting machine. This is of the wheel type, and is driven by an electric motor. It undercut a face 45 yards long in hard bind in three hours, of which one hour was occupied by the subsidiary work. Sixteen electrical horse-power was required.†

W. Fletcher ‡ describes the difficulties that he encountered in endeavouring to make coal cutting by machinery successful in collieries in Illinois. By systematising the labour and by educating the workmen, he has made possible the extended use of the Harrison percussive machine.

E. A. Sperry § gives an illustration of an electrically driven coal cutting machine with a tilting arm. The machine is of the chain cutter type, the chain running in a horizontal plane on an arm which can be swung in or out of the coal.

* *Transactions of the Federated Institution of Mining Engineers*, vol. vii. pp. 149-155, with one plate.

† *Colliery Guardian*, vol. lxvii. p. 846.

‡ *Journal of the Illinois Mining Institute*, vol. i. pp. 256-261.

§ *Ibid.*, pp. 209-210.

An illustrated description has been published * of the Jeffrey coal mining machine as used at the Cannock and Rugeley Colliery.

New Pumping Plant.—C. Schencke † describes in great detail the new subterranean pumping plant of the Drainage Company at Bockwa, near Zwickau. The company formerly controlling the drainage of the Zwickau Mines went into liquidation on June 30, 1887, and on April 16, 1890, it was decided to install a new plant, designed to raise 3300 gallons of water per minute from a depth of 600 feet. With the aid of thirty-three drawings to scale, the author describes the general plan of the work, the selection of the shaft section, the sinking and walling of the shaft, the excavation of the engine-room, the access of water, the ventilation, the pipes in the shaft, the plant at the surface, the boilers, the electric lighting plant at the surface, and the steam-engines. Full details of the cost are given.

V. Neukirch ‡ describes the dams erected in the collieries of the Oberhohndorf Company in 1891 and 1892. The total cost amounted to £3445. By obviating the cost of pumping, a very considerable saving has been effected by the Oberhohndorf Company, and by other collieries in the Zwickau district.

G. E. J. M'Murtrie § describes some recent alterations and additions to the pumping plant at the Foxes Bridge Colliery, in the Forest of Dean. The water in the pit is largely affected by the amount of rainfall, and recently the natural drainage has failed. In 1891 much water had to be wound, as the pumps were unable to cope with it. The plant now in use is a Cornish engine, with all the latest improvements. Plunger pumps with iron rods are employed, and a general description of the arrangements, aided by sketches, is given by the author. Some remarks on the above, and on pumping generally, are offered by H. F. Bulman.||

A. Demmler ¶ describes the underground pumping plant installed at the Hugo Mine, Buer, Westphalia, for raising 5280 gallons of water per minute to a height of 650 yards at a single lift. The engine is of the compound condensing type, and has been at work since February 1893. A second is now being put in as reserve. The engines and pumps are

* *Engineer*, vol. lxxvii. p. 26.

† *Jahrbuch für das Berg- und Hüttenwesen im Königreiche Sachsen*, 1893, pp. 1-39.

‡ *Ibid.*, pp. 108-136, with five folding plates.

§ *Journal of the British Society of Mining Students*, vol. xvi. pp. 35-48, with two plates.

|| *Ibid.*, pp. 85-90.

¶ *Bulletin de la Société de l'Industrie Minérale*, vol. vii. pp. 565-595, with four plates.

placed in a chamber some distance from one of the shafts, and arranged to preclude the possibility of their being drowned out. The high and low pressure cylinders are parallel, working on cranks at 90 degrees, and the pump cylinder is placed in front of the low-pressure cylinder. The diameter of the steam cylinders are 27·56 and 45·2 inches, the stroke being 47·2 inches. Particulars are also given of the receiver, condenser, air pump, air vessel, pump valves, and other parts. The steam supply pipe is 9·45 inches internal diameter, and that of the delivery pipe is 9·25 inches. The thickness of this pipe decreases from 1·77 to 0·59 inch at the top. From indicator diagrams, the ratio of work done is 82·5 per cent.

R. Thomson * describes a pump which has been in use at the Wilsontown Colliery. The ram and rods are hollow, and serve as the delivery pipes. One valve is placed inside the top of the ram, and the other at the bottom of the barrel. The rods through which the water is delivered pass through a stuffing-box at the top of the shaft. By disconnecting the ram from the pipes, additional lengths can be put in as sinking proceeds. The pipes are guided in the shaft by rollers, and can be led round slight curves.

The largest existing underground pumping engine is stated to be the twin tandem engine in the Kuxberg portion of the Mansfeld district, Germany. This has a double-acting plunger pump coupled to it direct. It has a high-pressure cylinder 37·4 inches in diameter, and a 53-inch low-pressure cylinder, with a common stroke of 51 inches. The plungers are 11·6 inches in diameter, and the engine, at a speed of 48 revolutions, is stated to raise per minute 600 cubic feet of a brine solution of the specific gravity of 1·2 to a height of 626 feet.†

The committee on the bearing surface of pump valves, appointed by the Mining Institute of Scotland, have recently issued their report.‡ Valves with leather-mounted seats gave the greatest rise of pressure due to cover; for metal and vulcanite lids there was no observed rise. The weight of the valve lids is of no practical importance, but the inertia of the water caused considerable rise of pressure above the statical pressure.

Two forms of electrically driven pumps have recently been illus-

* *Transactions of the Federated Institution of Mining Engineers*, vol. vi. pp. 534-537, with one plate.

† *Zeitschrift für das Berg-, Hütten- und Salinenwesen im preussischen Staate*, vol. xli. p. 597.

‡ *Transactions of the Federated Institution of Mining Engineers*, vol. vi. pp. 521-523.

trated.* One of these is designed for sinking. A float arrangement is fitted to these pumps, to cut off the current when the water sinks to a predetermined level.

An illustrated description has been published † of an electrically driven pumping plant constructed for the Shilbottle Colliery Company, Lesbury, Northumberland.

Unwatering Flooded Mines.—B. S. Randolph ‡ describes the operations undertaken for unwatering a flooded mine in George's Creek coal basin, Maryland. The coal lies in a flat synclinal basin, and was worked on the dip until the lower workings were flooded out. A shaft was then sunk at the lowest point, and headings driven from it to within about 100 feet of the dip workings in two seams of coal 40 feet apart. These drifts were joined by a staple pit, and a stone heading driven out of this to a point over the working. From this heading pipes were sunk in the floor, and furnished with valves to control the flow as soon as the borings reached the water. The pumps were then set to work in the shaft. During these operations it was noticed that air trapped in some of the rises had entirely escaped through 200 feet of solid coal under a head of 40 feet of water. In the same seam, air trapped under a head of 80 feet of water in an anticlinal dome had been unable to escape through slate rock at right angles to the stratification.

Delafosse§ describes the difficulties from water encountered in the Pisani shafts of the Trelys Collieries in France. The water was wound, but owing to the increase in the workings it was necessary to fix fresh guides in the shaft. Wooden guides in lengths of 15 feet, attached to three buntons, were decided upon, and then were put in position by means of a double-decked cage. Owing to heavy rainfalls the pits were flooded, and the author describes at considerable length the operations for removing the water, and subsequently putting in the guides after the water had been stopped back.

The Friction of, or Resistance to, Air Currents in Mines.—

D. Murgue,|| in addition to his previous paper on the friction of, or

* *Engineering and Mining Journal*, vol. lvi. p. 449.

† *Engineering*, vol. lvii. p. 350.

‡ *Transactions of the American Institute of Mining Engineers*, Virginia Beach Meeting, 1894 (advance proof).

§ *Comptes Rendus Mensuels de la Société de l'Industrie Minérale*, 1894, pp. 1-11, with map.

|| *Transactions of the Federated Institution of Mining Engineers*, vol. vii. pp. 211-221, with one plate.

1894.—i.

resistance to, air currents in mines, gives a number of appendixes dealing with the details of the experiments and of the calculations. The influence of the velocity and density of the air on the loss of pressure is calculated. The apparatus for correcting the anemometer is described. Calculations of the volumes are made, and the connection between the loss of pressure and the mean velocity is shown; also the curves of equal velocity are plotted.

Ventilating Appliances.—The Waddle fan and Corliss engine, erected at Seghill Colliery to replace furnace ventilation, is described by C. C. Leach.* The fan is 35 feet 1 inch in diameter, and the engine is supplied with steam at 100 lbs. pressure. The engine has one high pressure cylinder, 16 inches in diameter and 3 feet stroke, with separate end valve chambers, internal cylinder barrel, and steam jacket. The cylinder and covers are felted and lagged. Corliss valves, worked by the Inglis & Spencer gear, are used. The following table gives details of some tests :—

Revolutions of Fan per Minute.	Useful Effect. Per Cent.	Volume of Air per Minute in the Fan Drift. Cubic Feet.	Indicated Horse-power.	Pounds of Steam or Water per Indicated Horse-power per Hour.		Jacket Water.
				Measured into Boiler.	Accounted for by Diagram Card.	
20	35·12	49,686	6·46	...	...	...
40	51·02	87,940	29·61	35·57	24·34	5·17
60	54·78	135,742	96·11	27·12	21·50	2·54
60	54·12	247,702	154·35	...	...	...
67	...	...	209·20	...	...	...

In the furnace 1310 tons of coal was burnt per annum, as against 596 tons with forty revolutions of the fan, but part of the steam was used for other purposes.

It is generally held desirable to replace fans of large diameter by smaller fans, driven by high-speed engines, to increase their capacity. Such a fan is described by Ser.† It has a diameter of 9 feet 2 inches, and is driven direct by an engine giving 200 revolutions in the minute. This is a twin engine, with a piston velocity of 30 feet 6 inches, a stroke of 20 inches, and a cylinder diameter of a little less than 14 inches.

* *Transactions of the Federated Institution of Mining Engineers*, vol. vi. pp. 48-58.

† *Comptes Rendus de la Société de l'Industrie Minérale*, 1893, p. 115.

Further particulars are given by Mortier* of his fan, together with tests of one erected at La Péronnière Colliery, Saint Etienne. This fan is 2 metres in diameter by 1·2 metre wide (6·56 by 3·93 feet). In these fans the air traverses a chord of the revolving part, both entering and leaving at the periphery.

At the Bonifacius Colliery, near Krey, a new air shaft and ventilating fan were erected at a distance of 1420 yards from the two existing shafts, and as the waste gases of the coke oven plant erected near these gave sufficient steam for the power required, it was decided to utilise it for the transmission of power electrically to the new plant. A Capell fan was erected, and power is conveyed to it by two pairs of copper wires carried on iron posts. The total weight of the conductors used was less than 2 tons. Satisfactory results have been obtained.†

C. H. Higson‡ describes the Walker patent indestructible fan and engines at the Park Collieries, Garswood, giving particulars of their construction, arrangement, and efficiency. The engines run at 50 revolutions per minute, with a piston speed of 400 feet. They are of the twin compound condensing type. The stroke is 4 feet, and the diameters of the cylinders are 22 and 38 inches. Ordinary slide valves are used, with an adjustable cut-off valve on the high-pressure cylinder. Motion is transmitted by 15 cotton ropes each $\frac{5}{8}$ -inch in diameter, the driving and fan pulleys being 16 and 17 $\frac{1}{2}$ feet in diameter respectively. The fan is 24 feet in diameter, and 8 feet wide. It is built entirely of iron and steel, the vanes being secured by angle irons to the arms, which are held between two discs, made in halves, and placed so as to break joint on the fan-shaft. The anti-vibration V-shaped shutter is fitted to the fan. The edges of the vanes are made by attaching strips of pliable hoop iron, so that the clearance required is but small. A series of tests made in December last gave among others the following figures :—

Revolutions per Minute.	Air. Cubic Ft. per Minute.	Water Gauge of Fan. Inches.	Horse-power in Air.	Indicated Horse-power of Engines.	Useful Effect. Per Cent.
84·6	201,096	3	95·47	154·7	61·70
98·5	232,073	4	146·26	229·57	63·71
110·0	262,925	5	207·15	322·0	64·30
118·0	286,895	6	271·80	402·4	67·54

* *Bulletin de la Société de l'Industrie Minérale; Colliery Guardian*, vol. lxxvii. p. 544; compare *Journal of the Iron and Steel Institute*, 1892, No. II. p. 408.

† *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xli. p. 642.

‡ *Transactions of the Manchester Geological Society*, vol. xxii. pp. 468-485.

The boiler tests are also given.

A. H. Stokes * describes an improved form of water gauge. The two glass tubes are connected below through a brass cock which can be closed, so that the height of the liquid can be registered. A brass cup fits over the top of one tube, and can be removed for filling the gauge. The scale is placed at the back, and for the full width of the tubes.

Safety-Lamps.—An illustration has been published † of the Veitch-Wilson combined pricker and snuffer for safety-lamps. An extension of the pricker is added large enough to pass over the wick in order to clear off the crust.

V. C. Doubleday ‡ describes the Sussmann miners' electric lamp. It measures about $2\frac{3}{4}$ inches square and 8 inches high, weighing 3 lb. 11 oz. Reflectors are attached to concentrate the light, which will last for 16 hours. A secondary battery is used, and is protected by an outer case with elastic material inside.

Dr. H. Kämmerer and Dr. T. Oppler,§ with a view to determining the degree of safety presented by safety-lamps in the presence of inflammable air-mixtures which are met with in industrial occupations, made a series of experimental investigations. Seven lamps were tested in mixtures of Dowson gas, hydrogen gas, and other vapours. All the lamps except one were found to give satisfactory results, except with an explosive mixture of carbon disulphide and air, in which cases all the lamps, perfectly safe under other conditions, passed the flame.

J. W. Davison || describes a form of lever lock for safety-lamps. The casing is made in two parts, one of which is soldered or cast on the lamp and the other part attached by screws. The bolt which locks the lamp takes into a groove in a lug on the oil vessel. There are three spring levers which may be transposed.

The Detection of Fire-damp.—H. G. Graves ¶ gives a classified description of the various methods and apparatus that have been proposed for detecting fire-damp in mines. The use of these for showing the presence of other inflammable vapours in air is noted, and some

* *Transactions of the Federated Institution of Mining Engineers*, vol. v. pp. 474-476, with illustration.

† *Ibid.*, vol. vi. p. 448.

‡ *Ibid.*, vol. vi. pp. 264-268.

§ *Journal für Gasbeleuchtung und Wasserversorgung*, vol. xxxvi. pp. 101-104, 121-125.

|| *Proceedings of the South Wales Institute of Engineers*, vol. xviii. pp. 407-408.

¶ *Transactions of the Federated Institution of Mining Engineers*, vol. vi. pp. 241-256.

attention is also paid to the propositions that have been made for the destruction of the fire-damp in the mine, the pipe systems for draining off the gas, and the means for signalling the presence of gas. All these subjects are treated historically, references being given to the more important sources of information, and especially to the patents that have been applied for in this country. The apparatus for the detection and estimation of gas fall under three heads according to their method of action. These are gravimetric, diffusion, and combustion methods. The latter method is more fully treated under subdivisions, in which spongy platinum, photometric methods as in Liveing's indicator, or analysis as in Maurice's or Coquillion's apparatus, and safety-lamps are used. All the modifications of these different kinds of apparatus are briefly described, and the various drawbacks and advantages in their use are discussed. In connection with the use of pipes for draining off gas from the mine, there are many proposals for signalling or for taking samples, and these, together with electric methods of signalling, are commented upon. The author makes no suggestions for any new detector, but has only aimed at collating the numerous ideas into a form convenient for reference.

Chesneau * has found that the use of chloride of copper in his alcohol lamp has the disadvantage of clogging the wick by the formation of sub-chlorides. Nitrate of copper by itself does not give such good results as the chloride in the colouration of the flame, and it also forms a crust on the wick. By employing an organic chloride, however, in combination with nitrate of copper, all the advantages of the chloride result. The mixture preferred consists of one gramme each of pure crystallised nitrate of copper and bichloride of ethylene in a litre of alcohol.

At the Blanzy Collieries, according to D. de Dinechin,† the Chesneau lamp is used for estimating the fire-damp in the mine. The results are frequently verified by determining the point of inflammability according to the method described by L. Poussigue,‡ and the results thus obtained are further controlled from time to time by Le Chatelier's modification of Coquillion's apparatus.

E. Hardy§ has devised a form of fire-damp detector which gives an audible indication of the percentage of gas present. In this instrument two whistles are used, one being blown with pure air and the other with the air of the mine. Both whistles give the same note when the mine air is free from gas, but beats occur, on account of the difference of

* *Comptes Rendus Mensuels de la Société de l'Industrie Minérale*, 1894, pp. 24-26.

† *Bulletin de la Société de l'Industrie Minérale*, vol. vii. pp. 312-316.

‡ *Journal of the Iron and Steel Institute*, 1892, No. II. p. 414; 1893, No. II. p. 412.

§ *Comptes Rendus de l'Académie des Sciences*, vol. cxvii. pp. 573-574.

density, when gas is present. The number of beats is one in three seconds for 1 per cent. of gas, and four per second for 3 per cent. The whistle that is blown with pure air is enclosed in an air-tight casing through which the air is circulated by bellows, and another bellows is used for the other whistle. Both bellows are worked by springs.

This appliance is also described by G. Tissandier.* In another description,† it is compared with the "damoscope" invented by Professor G. Forbes and Mr. Blaikley, in which a similar principle was used. The influences that interfere with the correctness of this class of instrument are also discussed, the action of moisture and carbonic acid in the air, and of varying temperature and pressure being mentioned.

H. de la Goupillière‡ also comments upon the detector of Somzee, which also gives an audible warning.

A safety-lamp with alcohol flame for the detection of fire-damp is described by A. H. Stokes.§ The lamp is a modification of the Gray type. A small tube passes through the reservoir close to the wick tube, and is kept closed at its upper end by spring caps, and at its lower end by a screw plug. An alcohol lamp with a long wick tube replaces the screw plug when it is desired to make a delicate test, the wick tube passing through the tube in the reservoir, and projecting close against the main wick, from which it can be ignited. The main wick is manipulated by the pricker so as to light or be lighted from the alcohol flame, which is only used when small percentages of gas are present, larger proportions being tested for by the usual method. The back of the glass is blackened, and a screen may be used to cut off the light from the alcohol flame. The wick tube of the alcohol burner is 0.16 inch in diameter, and is protected when out of use by a cap. It carries alcohol enough for 120 tests of two minutes each. The height of the alcohol flame is 0.52 inch, or 13 millimetres, and the cap due to a percentage of gas below 1 per cent. may be seen.

The Gases Enclosed in Coal and Coal-Dust.—Dr. P. P. Bedson|| has published further results of investigations on the gases enclosed in coal and coal-dust in two papers, the second of which also bears the name of W. M'Connell, junr. A large number of analyses of the coal

* *La Nature*, vol. xliii. pp. 337-339.

† *Colliery Guardian*, vol. lxvi. p. 1024.

‡ *Ibid.*

§ *Transactions of the Federated Institution of Mining Engineers*, vol. v. pp. 462-473, with one plate.

|| *Ibid.*, vol. vii. pp. 27-53; compare *Journal of the Iron and Steel Institute*, 1892, No. I. p. 316.

and of the gases extracted are given. The samples of coal treated were taken from the Ryhope Colliery, the Seaton Delaval Colliery, the Backworth Collieries, the Hebburn Colliery, and another colliery on the Hutton seam. The gases were collected by heating the coal, both before and after crushing, in vacuo to various temperatures up to 180°C. , and were analysed. By using various temperatures, it is possible to separately extract the different gases of the paraffin series, the higher members being extracted at higher temperatures. The gases given by all the samples from the Hutton and Low Main seams are similar in composition and are rich in the higher hydrocarbons, which are firmly retained by the coal, and tend to render the dust inflammable. In the other coals, which are of more recent origin, the carbonic anhydride increases and the combustible gases decrease. Some experiments showed that charcoal and coal possessed the power of absorbing and retaining ethane, and that enclosed gases are liberated by diffusion into a lighter gas. Other experiments were made to determine the percentage of ethane necessary to make an explosive mixture with air.

Coal-Dust in Mines.—A blue-book has been issued containing a report made by Henry Hall, one of her Majesty's Inspectors of Mines, to the Royal Commission on Explosions from Coal-Dust in Mines, giving the result of a series of experiments made with coal-dust collected from the principal seams in various mining districts. Altogether fifty-two samples were received, and (with the exception of four or five) all were tested in a shaft of the White Moss Colliery, Skelmersdale, a wrought iron cannon being used for the gunpowder shots. The author says that the phenomena presented by these experiments as they progressed, and a careful examination of the detailed results, warrant the following conclusions :—

(1) That the flame from a blown-out gunpowder shot in the presence of dry coal-dust always ignites more or less of such dust, and so increases the burning and charring effects of the shot; (2) that when a large flame, such as that of a blown-out gunpowder shot, or the flame from the ignition of a small quantity of fire-damp, traverses an atmosphere containing a very moderate quantity of dry coal-dust, the dusty atmosphere will explode with great violence, and the explosion will continue on and pass throughout any length of such atmosphere, its violence and force increasing as it progresses; (3) that coal-dusts from several seams in different districts, notably those from Glamorganshire, Monmouthshire, Durham, Lancashire, Yorkshire, and Scotland, are almost as

sensitive to explosion as gunpowder itself ; (4) that coal-dust is, as a rule, more sensitive to explosion in proportion to its high quality and freedom from impurities ; (5) that a ready supply of oxygen, such as is supplied by a brisk ventilation, has the effect of making coal-dust explosions more probable and more severe ; (6) that certain high explosives are incapable of igniting or exploding coal-dust. Of the whole of the dusts tested, that from the Albion Colliery, Glamorganshire, excelled all others in violence and sensitiveness to explosion. This seam has the worst history of any in the kingdom, upwards of 1600 persons having been killed in it by explosions since the year 1845. It was also evident from the experiments, that the higher the quality of the coal seam, the more liability there is to explosions of dust. With regard to precautionary measures to be taken in face of these facts, the author urges the total abolition of gunpowder from coal mines, and the substitution of certain high explosives. Many of the largest firms in the country have, he says, already taken this step.

W. C. Blackett * discusses the subject of the combustion of coal-dust. The term combustion is preferred to that of explosion, although there is no difference except in degrees of force and speed in the definition of them. Not until the relationships between sympathy of vibration and detonation and explosion are determined, together with many other factors, can a proper understanding of colliery explosions be arrived at. The author describes the various stages of an explosion in which dust is concerned. First a shot stirs up a cloud of dust and ignites it. Its combustion causes air disturbances in all directions, and this stirs up the dust in advance, and so transmits the action. The explosion travels both with and against the air current, and it continues as long as the disturbance is vigorous enough to stir up the dust. In-bye, the increasing number of roads reduces the speed, and at the shaft the pressure is also relieved. The amount of dust present must be much larger than that chemically required to combine with the air in order to produce a large surface of contact, and in order to transmit heat from one particle to the next. There must be enough spare power in the shot to stir up the dust and to produce compression of the air. The dust must be fine and dry, and the flame from the shot must be large and hot. Possibly the shape of the road, temperature, and pressure of the air may also be controlling factors. Many of the experiments made on the surface are not satisfactory, as they do not comply with the conditions obtaining in the mine. After the first outrush of air there is an inrush, and the effects produced

* *Transactions of the Federated Institution of Mining Engineers*, vol. vii. pp. 54-63.

by this secondary cause mask the indications of the direction of the explosion, and this explains many observed vagaries. Finally, the author is of the opinion that high explosives will not fire coal-dust, but only slow explosives such as gunpowder, which are in sympathy with dust ignition, will do so.

C. Dunbar* is of the opinion that dust alone, without any admixture of fire-damp in the air, may cause explosions in collieries. He proposes that the roof and sides should be brushed, to remove the dust, at short intervals. The disadvantages of water in laying the dust are pointed out.

W. Glenn† describes several dust explosions which have occurred in the grahamite mines of Ritchie county, West Virginia. The grahamite, which is a form of asphalt, occurs as a vertical vein, and is worked by overhand workings which are driven up out of levels. Two serious explosions took place when the material was being blasted down with powder, and several smaller explosions took place when, on loading the material, the dust came into contact with the open lights. But very little fire-damp is found in the workings.

Spontaneous Combustion.—W. S. Gresley‡ refers to the difficulties of keeping dry walls tight in the Leicestershire and South Derbyshire coalfields, and also gives some particulars of gob fires in the United States. None of these fires appear to have occurred in any mine between Rhode Island and Indiana, nor in the coal regions of the Northern States and West Virginia. In Illinois and Iowa they give trouble. At Spring Valley Mines, in Northern Illinois, fires occur after a lengthy stoppage, but not otherwise. In Iowa, railway embankments of unsaleable coal screenings often fire and give much trouble. The moisture in the coal in all instances greatly affects the liability to combustion, simply damping a heap of slack and covering with clay sometimes causing it to take fire.

Stoppings in Underground Roads.—E. B. Wain§ describes his experiences in building stoppings in underground roads. Some seventeen stoppings had to be built in a seam about $7\frac{1}{2}$ feet thick lying at 20° dip on re-opening workings closed by explosion and fire, and subse-

* *Transactions of the Federated Institution of Mining Engineers*, vol. vi. pp. 372-376.

† *Transactions of the American Institute of Mining Engineers*, Virginia Beach Meeting 1894 (advance proof).

‡ *Transactions of the Federated Institution of Mining Engineers*, vol. vii. pp. 206-210.

§ *Ibid.*, vol. vi. pp. 572-577, with two plates.

quently flooded. Some of the workings above water-level showed abnormal heat, and were directly connected with large goaf areas full of gas. The stoppings in the simplest cases consisted of two walls 3 feet in thickness and 6 feet apart, with well-rammed sand between them. They were built to present the convex side to the rise workings, and were let at least 2 feet into the coal, and both roof and floor were excavated until solid ground was reached. Full details of the work are given, together with several illustrations.

Photography in Coal Mines.—H. W. Hughes * describes his experience in photographing underground in coal mines. A large number of successful photographs have been produced, although with much difficulty, in the thick coal seam of South Staffordshire. Photographs have also been taken by A. Sopwith in the 5-foot seam of the Cannock Chase, and by Bretz in the Pennsylvanian coal seams. In metal mines, J. C. Burrow has taken successful views in Cornwall. In the 10-yard seam the author uses rapid lenses and powerful illumination by the aid of magnesium wire, or powder burnt in special lamps, two sources of light being used to obviate the production of dense shadows.

Further particulars of less technical character are given by the author † in a second paper, in which he deals generally with the methods that he adopts, and describes the cameras, lenses, plates, and means for illumination and for development, that he uses.

Temperature and Water in Deep Collieries.—J. Libert ‡ offers the results of some observations on the temperature and the nature of the waters in deep collieries. Some of the temperature observations were made at a depth of 1150 metres (3672 feet), and showed 47° C. at the bottom of a shaft at the Produits Colliery, Flenu, and 40° C. after three months, due to the ventilation. The rate of increase is compared with that found by other observers. Hot-water springs were found in these workings. Analyses of the waters are given, showing high percentages of magnesia salts.

The Development of Coal Mining.—R. Nelson Boyd, § in a paper on collieries and colliery engineering, traces the development of this

* *Journal of the Photographic Society of Great Britain*, vol. xviii.

† *Transactions of the Federated Institution of Mining Engineers*, vol. vii. pp. 164-179, with plate.

‡ *Annales de la Société Géologique de Belgique*, vol. xx.

§ Paper read before the Society of Engineers, November 6, 1893.

industry. After briefly alluding to the old workings before the introduction of machinery, it is pointed out how rapidly the development of the coal trade took place after the steam-engine was invented, a development which led to the introduction of the tramway and railway. The increase in the depth and extension of the pits produced greater dangers from explosions, which led to the invention of safety-lamps, and the introduction of mechanical means of ventilation. The application of wire ropes to underground haulage is then referred to, as well as the improvements in shaft arrangements for raising the coal. The various methods of working the coal, and the use of modern explosives, are discussed; and the author passes on to the consideration of the mechanical means of cutting coal, and the modern electrical installations underground for various purposes. The effect of the introduction of machinery on the number of men employed is alluded to, and after noticing the quantity of coal transported on the railways, the subject of the duration of the coalfields, and the necessity for economy are treated. The possible introduction of petroleum as an adjunct to coal, and the reserves of peat which might come into use are discussed. The author concludes by a reference to the technical development of the collieries, which has enabled the output of 10 millions of tons at the beginning of the century to be raised up to 182 millions of tons in 1892.

Early Scotch Mining.—In a lecture at Muirkirk, R. W. Cochran-Patrick dealt with mining in Scotland in early times. Every known mineral was recorded in that country, but the only metal of which he had not been able to find satisfactory records of working was tin, though it was mentioned in several Acts. Coal was worked at an early date, and a description of it and of the workmen was given.*

The History of Coal Mining in Pictou County.—The Rev. Dr. Patterson † reviews the early history of coal mining in Pictou county. Coal was here first discovered in 1798, near Stellarton, and in the same year a small quantity was worked, but it did not prove to be of good quality. Licenses were soon after taken out from the Government to work coal, and in 1802 a pit was opened on the M'Gregor seam. In the earliest grants of land, the mines of gold, silver, and coal were reserved to the Crown, and later on lead, copper, iron, and all other minerals were similarly reserved. In all cases, coal is therefore now Government

* *Colliery Guardian*, vol. lxvii. p. 415.

† *Transactions of the Mining Society of Nova Scotia*, vol. ii. pp. 57-62.

property. In 1807 a license was granted to dig and also to export coal, and what is now known as the Big seam was discovered, although not at the time worked. In 1815, 650 chaldrons of coal were exported. After the peace, coal fell in price to half the value, and from 1818 to 1827, the average output was 2200 chaldrons. In 1825 all the reserved mines were leased to the Duke of York, and subsequently these passed into the hands of the General Mining Association. This company finally acquired all the coal mines in Nova Scotia, and in 1827 commenced operations in earnest. A foundry was erected in which tram rails were cast, and about 1830 the first steamer was loaded in the harbour. In 1839, a railway about 6 miles long was opened, and worked until 1886. Soon after the arrangements for working coal were completed, the Association erected a small blast-furnace near the mines, but did not work it for any length of time. Hæmatite from Blanchard was used, and also surface limonite from Bridgeville; but the vein of ore at the latter place was not discovered until much later. In 1856 the monopoly owned by the Association was abolished, and thenceforward great activity was exhibited in exploring for and working coal.

Coal Mining in Bosnia.—F. Poech * observes that mining was pursued in Bosnia at the time of the Romans, and in the fourteenth century the Republic of Ragusa imported into Bosnia miners from Saxony. The advance of the Turkish conquests destroyed the industry again, with the exception of some very primitive iron forges and salt-works. Since the Austrian occupation, the mining industry of Bosnia has made rapid progress.† This is especially true of the coal industry. In a map which accompanies the paper, it is shown that the coalfields of Bosnia are numerous, and that they cover a considerable area. The existence of bituminous coal deposits of commercial value is unknown, and is doubtful from geological reasons, but lignite and brown-coal occur in very remarkable quantities. In some localities the brown-coal closely resembles in quality a bituminous coal. These brown-coals mostly occur in the more recent tertiary beds, and usually the fuel varies in character with increasing depth from that of lignite to that of a dark lustrous brown-coal. The most important of the known deposits is that of the Zenica-Sarajevo district. This deposit is about 50 miles in length by 9 to over 12 in width. The geological age of this tertiary basin is not yet definitely known. Another similar, though smaller, coal basin exists about

* *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xli. pp. 313-319.

† Compare *Journal of the Iron and Steel Institute*, 1893, No. II. p. 545.

22 miles to the north, and others are also mentioned, the map showing the existence of no less than twenty-five. The percentage of water shown in a table giving particulars as to the coal of 15 seams, varies from 2·53 to 17·8, though in only two cases is it less than 9 per cent.; the percentage of ash shown varies between the limits of 1·95 and 15·5; and that of sulphur up to 3·35. The calorific value varied from 3546 calories in a brown-coal containing 16·3 per cent. of water, to 7168 in a brown-coal with only 2·53 per cent., this latter being not of recent tertiary formation but an Eocene deposit.

The history of the industry is briefly referred to, and annual statistics given for various districts for the years 1880–1892, the total output having risen from 263 tons in the former year, 16 men being employed, to 18,536 tons in 1892, when employment was afforded to 390 work-people.

The author then proceeds to describe the Zenica Colliery in considerable detail. Three seams have been worked. The most important of these seams is 33 feet in thickness, while another is 13 feet. In 1892 this colliery gave employment to 122 workpeople. The Kreka Colliery, to which he also refers, was begun in 1885. There are two seams of brown-coal, the one 60 feet and the other 28 feet in thickness, separated by a course of sandstone 138 feet thick. The methods of mining and the working conditions are described.

The Westphalian Coalfields.—The Rheinelbe No. 1 shaft in Westphalia is a little less than 15 feet in diameter. It is 1181 feet in depth.* The winding is effected by an engine with a cylindrical drum 19 feet 8 inches in diameter. Three-decked cages are used, taking 6 waggons, each of which has a capacity of 128 gallons. The second shaft is 13 feet in diameter, and 1083 in depth. It is placed at a distance of 115 feet to the south of the first shaft. The winding engine has a conical drum, and while a 3-decked cage is again used it is only large enough to hold 1 waggon, of the same capacity as before, on each platform. Through the two shafts, 1600 tons of coal are wound in two 8-hour shifts. The haulage in this colliery is effected by ponies, 83 of which are at work. The ventilation is done by a fan placed below ground. It is on the Pelzer system, and is 11 feet 6 inches in diameter. It is worked by power brought down electrically from the surface, a current of 800 volts and 125 ampères being employed. With this amount of driving power, the capacity of the fan is 106,000 cubic feet of air per minute.

* *Stahl und Eisen*, vol. xiii. p. 748

Above ground the works are lit by the electric light, 14 arc and 750 incandescent lamps being in use. Steam is raised by the aid of a battery of 12 Cornish boilers.

The Zollverein Colliery, Gelsenkirchen.—This colliery has four shafts, the oldest of which dates from 1847, while the most modern was only begun in 1891. The maximum output of this colliery hitherto was that attained in 1891, when it reached 1,155,000 tons, 2725 men being employed. The coal raised was gas coal, long-flame gas coal, and caking coal, part of which was converted into coke. A large briquette-making plant exists at this colliery. The boilers at the most modern shaft work with 10-atmospheres excess pressure, while at the older shaft it is less than half this.*

IX.—COAL-WASHING.

Screening and Cleaning Coal.—G. E. J. M'Murtrie† compares some of the systems of machine screening, and describes the screens lately put down at the Foxes Bridge Colliery, Forest of Dean. The screens compared are jigger screens with lengthway motion; jigger screens with cross motion, or the Lyall screen; the Greenwell screen, with endless chains travelling between stationary bars; and Chambers' screen at Denaby Main Colliery. The latter screen, which is illustrated, consists of a number of parallel longitudinal meshed bars carried on pins rocking in inverted steps provided in the bars, and connected to a rocking shaft at either end. Vertical and lateral movement is imparted to the bars through rods and levers from eccentrics on a revolving shaft. The advantages of this screen are shown, and those of the Briart and of the Greenwell screens are commented upon. It is held that the Briart screen takes the greatest tonnage; the Greenwell screen is cheapest in first cost and maintenance; whilst the jigger screen with lengthway motion, associated with proper picking belts, seems to treat the coal best. The latter system was therefore adopted at the Foxes Bridge Colliery. The coal treated is 500 tons per day from five thin seams. On account

* *Stahl und Eisen*, vol. xiii. p. 685.

† *Journal of the British Society of Mining Students*, vol. xvi. pp. 69-78, with three plates.

of the different qualities, two jigger screens and three belts were put down. The first screen makes four sizes, that over 4-inch going direct to the trucks; coal over $1\frac{1}{2}$ -inch and over $\frac{3}{4}$ -inch pass on to two separate picking belts, and coal under $\frac{3}{4}$ -inch is loaded direct. On the second screen three sizes are made, coal over $1\frac{1}{2}$ -inch being picked on a separate belt, and that over $\frac{3}{4}$ -inch being treated on the same belt as is used for the first screen. Full details are given of the dimensions and arrangements of the various screens and belts, which are 44 feet long, one being 3 feet and the other two each 2 feet wide.

J. C. I'Anson* describes the Lührig washing plant at Motherwell, near Glasgow, for treating 1500 tons daily. The tubs are discharged to vibrating screens with 2-inch round holes. The coal that passes over the screens is received on steel link picking belts, where the slate is removed by hand. Further quantities of small coal are removed on this belt, and are treated with that which passes through the vibrating screen into a hopper underneath. This hopper has a capacity of 100 tons. The coal is taken from it to a sizing drum with concentric shells of differently sized meshes, which makes three sizes of nuts, pea, and smaller sizes. Each size of nut coal is treated separately in jigs. The dirt and shale from the washers is crushed and re-washed. Washed coal is delivered over perforated shaking shoots, which drain it and convey it to the loading hoppers. While the coal travels down these shoots, it is sprayed with a fine jet of water. The small coal, from $\frac{5}{16}$ inch downwards from the sizing drum, meets the overflow water from the nut washers, and is carried to grading boxes, where it is deposited according to size. Each size is washed separately on felspar washers. The washed fine coal passes to a revolving copper drum, perforated with holes $\frac{1}{4}$ inch in diameter. The sludge and water which pass through are led to the sludge-recovery tanks, whilst the coal above $\frac{1}{4}$ inch size is conveyed by elevators with perforated buckets to storage hoppers, and is subsequently coked or otherwise disposed of. In practice it has been found that the ash in the fine washed coal does not exceed $2\frac{1}{2}$ per cent., the coal in the waste falls below 1 per cent., and the cost of labour is one halfpenny per ton. The results at several other plants are also given.

This plant is also described by J. Hogg,† who gives the results of a week's work and the cost of washing. In this week 2659 tons of

* *Transactions of the American Institute of Mining Engineers*. Discussion (advance proof), 1893.

† *Transactions of the Federated Institution of Mining Engineers*, vol. vi. pp. 393-397, with one plate.

raw material was washed in thirty-five hours, with the following results :—

	Raw Coal.		Washed Coal.	
	Tons.	Per Cent.	Tons.	Per Cent.
Treble nuts	511	19·21	511	21·85
Double nuts	544	20·46	544	23·26
Single nuts	895	33·66	895	38·26
Pearl dross	139	5·23	139	5·94
Mixed pearl and sludge	250	9·40	250	10·69
Rubbish	320	12·04	...	...
	2659	100·00	2339	100·00

The cost of the washing is given as 0·54d. for labour and 0·25d. for stores, steam, &c., or a total of 0·79d. The profits are also considered.

F. Baum * describes the Baum coal washing plants at Middleton Colliery, near Leeds, and at West Riding Collieries, near Normanton. All the coal to be washed is preferably separated out by one size of screen, and stored in a hopper, whence it is drawn off to be sized in a multiple rotating drum, with five screening surfaces. This is done dry, and the coal is then carried by water currents to the coarse and the fine jigging machines, of which there are four and two respectively in the battery. The jigs are built of iron, and their special feature is that the pulsation is produced by alternately compressing and exhausting the air on the side of the machine where the piston is usually placed, this side being closed for the purpose. The coarse machines are driven at 50 to 70 strokes per minute, and the fine machines at 75 to 110 strokes, the speed adjustment being made by coned pulleys. The screens in the two jigs are of $\frac{3}{8}$ and $\frac{1}{4}$ inch, but the slate in the fine machine forms a bed. The action of the machines is then dealt with by the author in some detail. In piston jigs the greatest velocity is at the centre of the stroke, but in these jigs the compressed air is admitted continuously, so that the rise of the water is continuously accelerated. On the return, there is no suction owing to the piston, but the water falls owing to the difference of level on the two sides of the partition, a difference equivalent to $1\frac{1}{2}$ to 2 lbs. per square inch, instead of 15 lbs. By throttling the air supply, any desired difference of level may be produced.

The washed nuts are led by water currents to loading pockets, which

* *Transactions of the Federated Institution of Mining Engineers*, vol. vii. pp. 156-163, with one plate.

are filled with water. After they are full the water is drained off, and then the coal is loaded through slides in the bottom. Two pockets are used alternately. The washed fine coal is taken by water to draining screens, through which the finest coal passes. The coarser coal is led to disintegrators, where it is ground for coking. Some of the nuts are also ground, if necessary, for this purpose. The small fine coal is separated from the water in pointed filtering boxes, and is also sent to the coke ovens. Two sets of these boxes are used, and the water from them is used in the coarse jigs. About 10 per cent. of the water is replaced by fresh, for use in the fine jigs. A 30 horse-power engine drives the plant.

Illustrations have been published * of a coal washing plant on Sheppard's system, erected to treat 350 tons daily at the Bridgewater Collieries. Three sizes are treated separately. All coal below $\frac{3}{8}$ inch square mesh is washed in five compartments of Sheppard's felspar jigs. The coal is jigged first in one box and then passes over a dam into the second box, where it is finally treated. The boxes are hung on a beam, so that they balance one another, and the jiggling motion is given to the boxes themselves, and not by a separate plunger. The dirt is lifted continuously from these jigs by a screw and elevator, but the other machines have a valve discharge.

J. C. Jefferson† describes several of the forms of machinery used for washing coal, chiefly those in which a jiggling action is used. The action of the flow of the water on the different sizes of coal and dirt is explained.

D. Graillot‡ describes one of the plants at the Blanzey Collieries for treating 20,000 hectolitres of coal per day of eleven hours. The tubs are raised by direct-acting steam lifts to a height of 25 feet, where they run automatically from the cage and pass to the tips. The empty tubs are lowered by a balance cage. Coal above 2·3 inches is hand-picked, below that size it is washed. The coal, as it is emptied from the tubs, falls on to shaking screens placed in four groups of three each. Each screen receives 110 oscillations per minute, and is perforated with holes 2·3 inches in diameter. The large coal falls on to a picking belt about 25 feet long, where it is picked over by boys. Clean coal is left on the screen, whilst the stuff removed is separated into three classes, namely, coal of second quality for sale, inferior coal for the boilers, and stone. The small coal

* *Colliery Guardian*, vol. lxvii. p. 832, with one plate.

† Paper read before the Leeds Association of Engineers, *Industries and Iron*, vol. xv. p. 855.

‡ *Bulletin de la Société de l'Industrie Minérale*, vol. vii. pp. 293-298, with plates. 1894.—i.

which passes through the screens falls into hoppers holding 2000 hectolitres, whence it is removed by screw conveyors to bucket elevators which deliver it to the washing plant. A Corliss engine of 250 horse-power is used to drive the plant, the power used being distributed as follows:—Electric lighting 45, screens 15, elevators 47, washing machines 39, pumps 24, endless chain for tubs 2, loss in transmission 25.

The washing plant mentioned above is described in detail by D. de Dinechin.* The sizes treated are 0 to 9 mm., 9 to 23 mm., and 23 to 60 mm. (0 to 0·35, 0·35 to 0·91, and 0·91 to 2·3 inches). The washery for the briquette plant consists of four groups of washers on the Ract-Madouse system, each group with three double jigs, and one group on the Lemièrè system. Each group is entirely distinct, with its own trommel for making the above sizes. The washing plant at the Mau-grand pits consist of three groups of screens and jigs.

Coal of the size of 0 to 9 mm. (0 to 0·35 inch) is further separated in a trommel, with the aid of a stream of water, into three sizes—0 to 5, 5 to 7, and 7 to 9 mm. (0 to 0·2, 0·2 to 0·28, and 0·28 to 0·35 inches), and these are treated separately on felspar washers. The larger sizes are treated on Ract-Madouse jigs. The No. 3 washery, which was built in 1889–90, is the most complete, and consists of four distinct groups of screens and jigs. Two of these groups contain Lemièrè washers for all sizes, and two groups have felspar jigs for small sizes, and Lemièrè washers for larger sizes. Double Lemièrè jigs are used for larger sizes and single jigs for the smaller size. The same system of sizing is used as above indicated. After washing, the clean coal is lifted by elevators to draining-towers. The large and medium size is, however, passed over a shaking screen under a jet of water to remove any fine coal that may have been formed in its passage. The circuit of the water, the settling ponds, and the means for removing the mud are also described.

Methods of coal-dressing employed in the anthracite regions of Pennsylvania are described, with the aid of seven drawings, by Professor W. Schulz.†

W. Stein‡ describes the coal washing plant at the new blast-furnace works at Ferrona, Nova Scotia. This plant has been at work since May 1892, and supplies a set of coke ovens which turn out about 175 tons of coke daily. The coal from the mine is tipped into two pits, whence it is taken by bucket elevators to a shaking screen with a double eccentric

* *Bulletin de la Société de l'Industrie Minérale*, vol. vii. pp. 299–316.

† *Glückauf*, vol. xxx. pp. 67–71, 87–91, 122–123.

‡ *Transactions of the Mining Society of Nova Scotia*, vol. ii. pp. 78–79, with plate.

motion. The mesh of the screen is $\frac{3}{4}$ -inch. Coal which passes over this screen is passed through rolls and returned. Fine coal is taken by a bucket elevator to a revolving screen making three sizes. These are separately treated on double felspar jigs with variable stroke. Washed coal is taken by a perforated bucket elevator to a storage tower, and dirt is loaded by an elevator into railway trucks. A 100-horse-power steam-engine drives the whole of the plant. The coal contains as much as 17 to 35 per cent. of ash, and $2\frac{1}{2}$ to 3 per cent. of sulphur before washing, and averages 10 per cent. of ash after washing, and 1.35 per cent. of sulphur.

A coal washing plant* of 600 tons capacity has been in operation for two years at Hondo, Coahuila, Mexico, for supplying marketable coal and seventy-five coke ovens. The coal from the mine is tipped on to a screen with $1\frac{1}{2}$ -inch openings, the larger coal falling direct into the railway waggons. The finer coal which passes through this screen is weighed on its way to the bins, whence it is taken to a large revolving screen. The large coal from this screen is treated on two jigs, which yield nut coal for locomotive purposes. The fine coal is further sized by revolving screens into four sizes, which are then jigged, except the smallest size, which is treated by a hydraulic classifier, which subdivides it further into three sizes that are treated on slime jigs. The washed coal is drained in a revolving screen, and together with the slime coal caught in settlers is taken to the coke ovens. Clear water is used for jigging the fine coal, but for the large sizes the same water is used over and over again, being circulated by a centrifugal pump.

Re-working Anthracite Culm Banks.—A. W. Sheaffer† states that the question of deterioration does not play an important part in reducing the amount of anthracite in the culm banks in the Schuylkill region, Pennsylvania, as was expected by E. B. Coxe. In this district a large number of washeries have been installed, and the author gives the results obtained from the Stanton culm bank from 1889 to 1892, and from other operations. The banks worked vary in quality, but as far as statistics are available the records show that from 40 up to 70 per cent. of the stuff is marketable. Much of the smaller sizes are still wasted, as there is but little demand for them. The following table is

* *Colliery Engineer* (Scranton), vol. xiv. p. 88.

† *Transactions of the American Institute of Mining Engineers*, Virginia Beach Meeting, 1894 (advance proof).

compiled from a series of seven tables given provisionally, more data being promised :—

Culm Bank.	Year.	Marketable Coal in Bank.	Stove.	Chestnut.	Pea.	Buckwheat.	Total.
		Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Tons.
Stanton . .	1889	...	20.59	16.74	14.24	48.42	25,262
" . .	1890	...	14.21	20.35	15.55	49.89	62,808
" . .	1891	...	4.25	13.89	21.97	59.89	72,074
" . .	1892	...	5.37	9.40	21.91	63.32	50,151
Draper . .	1891-2	42	7.93	14.26	14.76	63.05	47,620
" . .	1892-3	50	2.60	12.40	14.69	57.22	37,187
Furnace . .	1892	40	8.58	7.39	23.27	60.76	23,734

In addition, the Draper culm bank yielded 13.09 per cent. of rice-size in 1892.

The Use of Small Sizes of Anthracite.—A great deal of the difficulty arising in the use of small sizes of anthracite, according to E. B. Coxe,* is caused by the want of uniformity in the size, the amount of ash and moisture, and the composition generally. A rapid method of determining the commercial value of small sizes is described by the author. At each colliery samples are taken several times a day and are put into separate bins, one for each size. The coal in each bin is mixed and quartered down to about 30 lbs. which is used for determining the size, the slate, the ash, the moisture, and the specific gravity. The size is determined by sifting in a box with a number of superposed screens in the form of drawers. The whole of the sample is placed in the box, which is given a rotary and conical motion. The slate is separated by a solution of 1.75 specific gravity made by dissolving zinc in hydrochloric acid and evaporating. The solution can be filtered through mineral wool to free it from coal-dust. For the ash, half the sample is dried and ground in a revolving cylinder containing chilled iron balls. The ground coal is quartered down and the sample taken is treated to pass a 60-mesh sieve. Moisture is determined by drying the sample in a copper muffle heated to 225° F. by small gas jets. Specific gravity is determined by weighing about 20 lbs. in air and in water.

The Manufacture of Briquettes.—D. de Dinechin † describes the washing plant and the briquette factory at the Blanzly Collieries. It was

* *Transactions of the American Society of Mechanical Engineers*, vol. xv. (advance proof).

† *Bulletin de la Société de l'Industrie Minière*, vol. vii. pp. 299-312.

this company which first commenced to make briquettes in the year 1845. Tar was then used, and briquettes of about 20 to 22 lbs. were made in hydraulic presses. After compression, they were dried in stoves. At the present time there are two works, one with three Revollier presses, and the other with four Biétrix presses. Coal from 0 to 9 mm. (0 to 0.35 inch) in size, containing 14 to 15 per cent. of water, is delivered by an elevator into a Carr disintegrator which is also fed with pitch by a second elevator in the proportion of 9 per cent. Screw conveyors take the mixture to steam heaters, where it remains for 8 to 10 minutes, and it then falls into the moulds. Each Revollier press makes 8 tons of briquettes per hour, containing about 3 per cent. of water. The Biétrix press makes one briquette at a time, so that for rapid production the coal has to be dried before it is compressed. The processes are described in detail.

B. Müller* is stated to manufacture briquettes by moistening the fine coal with from 5 to 12 per cent. of water, and then subjecting the mass to a pressure exceeding 800 atmospheres.

The Transport of Coal in Pipes by Water.—At the Chicago Exhibition† there was a small exhibit intended to demonstrate the feasibility of pumping coal to market in the form of sludge. In this method it is intended to reduce all the coal to a fine powder, to remove some or all of the impurities by washing, to mix it with about its own weight of water, and in this state to pump it any desired distance, and then to free it from most of its water in settling tanks. When 10 to 20 per cent. of water only remains, it is possible to pump it to the points of consumption, where the remainder of the water may be removed by the aid of waste heat. Experience with oil has shown that pumping is an efficient and cheap method of transport, but there is the disadvantage that with coal only half the weight moved would be "live" weight, besides which the wear in the pipes would certainly be greater than with oil, which practically causes no wear. The low specific gravity of all coal renders its admixture with water easy. At 1200-lbs. pressure for pumping stations 30 miles apart, the calculated tonnage capacity for a 2-foot pipe is 28,000 tons, taking a cubic foot of mixture to hold 35 lbs. of coal. The waste from slack would be reduced by this system, as there would be no inducement to leave it underground, and the factor of breakage loss is also removed. No useful constituents of coal are

* *Glückauf*, vol. xxix. p. 1409.

† *Engineering News*, New York, vol. xxxi. pp. 159-160.

soluble in water, but moist pulverised coal suffers rapid deterioration in air, so that it would have to be kept under water to remove this loss and the liability to spontaneous combustion. The difficulty is to free the coal from the water, but it is somewhat remarkable that, even if the coal were burnt in the wet state, the loss of heat from the vaporisation of water would not exceed 8 to 12 per cent. It is proposed to use settling tanks, but other means are available, such as centrifugal machines. Already it has been shown that dust coal can be burnt with economy, and another way of utilising it is to mix it with fine iron ore, and to press the mixture into briquettes.

It may be noted that another method of conveying coal was also shown. In this system the coal is carried by a current of air supplied by a Root's blower, the coal being fed into the exit pipe from the blower. It was stated that the wear on the pipes is small, and that not only dust but also larger sizes of coal may be conveyed in this way.*

The Shipment of Coal.—S. W. Allen † describes at considerable length the various arrangements used for shipping coal in this country. The early history is more closely connected with the north of England and Scotland, where hand loading, first of all, and then gravitation methods were employed. In the latter system, the waggons are run on to a staging or staith, and discharge their coal through folding-doors in their bottoms, and an opening between the rails into hoppers underneath. Thence the coal is led to the holds through shoots, which are provided with adjustable doors to govern the speed. To allow of loading at all stages of the tides, these staiths are made higher, and the spouts are made adjustable, openings being also made in the hoppers at various heights. Owing to the narrowness of the spouts, they can be made to cover a large area. Probably the most elaborate plant on this system is that at Hendon Dock, Sunderland. When the coal does not slide easily, or when the lumps are too large, various means have been adopted to lower the waggon bodily on to the deck of the ship. Several of these machines are at work on the Tyne. In one form the waggon is brought on to a cradle, swung from two jibs, which fall forward and carry the cradle over the hold, where the waggon is discharged through its bottom doors. The descent and return of the jibs is controlled by a pendulum counterpoise. In another form the cradle is swung at the end of

* Private communication by H. G. Graves.

† Paper read before the Institute of Marine Engineers, February 24, 1894 (advance proof).

cantilevers, and in still another form the cradle or platform is lowered vertically, instead of in the arc of a circle, by ropes which are connected over pulleys to counterweights. A somewhat similar plan to that last mentioned is used for end-discharging waggons, which are tilted as they are discharged. As ships increased in size, however, the fall into the hold becomes too great for these methods. Until a recent date, tubs containing 2 tons were employed. These tubs were fitted into a barge or keel, or carried on a wheeled underframe, and were filled from the trams. In order to load a ship, the tubs were lifted off the barge and lowered direct into the hold, where they discharged through their bottoms. In some instances the barges themselves carried the lifting machinery necessary. This method was, in the author's opinion, very perfect as far as the minimum of breakage was concerned, but it was too slow. Reference is then made to the proposals made in 1850 by Laird & Cowper for the use of endless travelling belts in loading coal. The machinery at the East and West Bute Docks, Cardiff, and at Penarth Dock, are then described. Here the waggons are received on a cradle, which is lowered and returned by ropes connected to counterweights, and tipped so as to discharge at the end. To form a conical pile in the hold, in the first instance, a box holding a ton is used, and all its motions are also controlled by a counterweight.

At Cardiff, Barry, Newport, and Swansea docks, hydraulic power is used, and several of the various arrangements are shown and illustrated. In some forms the rams act directly, in others through rope-gearing. The same ram that lifts the cradle can also be employed to tip the waggon. At the Barry docks all the water used is returned, some of it to the high-pressure mains by the weight of the descending waggons, and the remainder goes back to the engine-house through a series of pipes. All the forms described above are fixed tips; but much ingenuity has been expended in arrangements for loading the vessel at any desired point without moving it. Butler's design for a tip which is movable bodily along the dockside is mentioned, and also the turntable with curved lines at Roath basin, Cardiff, and the traverser system at Alexandra Dock, Newport, are described. A movable crane, which lifts the waggon bodily, is used at Bute Docks, Cardiff. Several other arrangements are also mentioned.

Next to the old system of separate boxes discharged directly at the bottom of the hold, the method of shipping with a large anti-breakage box placed at the mouth of the shoot is preferable. The shoot may be of any length, but it should be kept full of coal, and the box should be

as large as possible. Modern hydraulic cranes for lowering the full antibreakage box are no advance on the old counterbalance methods, unless they are arranged to pump water into the pressure mains on the descent of the box. Movable coal-tips are certainly the ideal method for rapid shipment, as coal can be loaded into every hatchway at the same time, but in practice the fixed tips do the work fast enough. When proper care is taken in using the anti-breakage box, as little breakage occurs as in any other arrangement.

PRODUCTION OF PIG IRON.

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I.—BLAST-FURNACE PRACTICE.

Carbon Reactions in the Blast-Furnace.—W. J. Hudson * presents a useful summary of what is known of carbon reactions in the blast-furnace. Not a great deal of original matter is contributed to the discussion, but attention is devoted rather to condensing the opinions of the best authorities and the literature of the subject that is scattered over such a wide area. The results of various experiments by Sir Lowthian Bell and others are given, and the various reactions between carbon, oxygen, and oxides of iron are fully entered into. The author does not attach great weight to the effects of deposited carbon. If the escaping gases contain less than the theoretical amount of carbonic anhydride, it does not follow that it is due to reduction by solid carbon, but is probably the result of deoxidation by monoxide in a red-hot region. Any of this carbon not decomposing carbonic anhydride may combine with the iron or may descend to the tuyeres, where it is burnt. The results of some experiments on this point are given.

The Utilisation of Iron Ores.—B. Osann † observes that the importation of foreign iron ores into Germany is becoming yearly of more and more importance. The practical value of an iron ore, he adds, is

* Paper read before the South Staffordshire Institute of Iron and Steel Works Managers, March 3, 1894. A copy of this paper has been presented by the author to the library of the Iron and Steel Institute.

† *Stahl und Eisen*, vol. xiii. pp. 986-991.

largely dependent on its cost, but in addition to this must be considered the expense or saving accompanying its use in the blast-furnace. The cost of a ton of pig iron comprises : (1) the cost of the ore ; (2) that of the coke ; (3) that of the flux ; (4) the wages paid ; (5) charges for raising steam and for other machinery ; (6) general expenses. As to the ore, he points out that in every 1000 units of pig iron produced, there are usually 70 of manganese, carbon, &c., and the amount of iron which passes into the slag is about equal in quantity to the iron contained in the ash of the coke charged. The author proceeds to consider the question of the calculation of the furnace charge. Silica, of course, is the acid ; lime, magnesia, and ferrous and manganous oxides the bases. Alumina, he considers, is a weak base. Some consider it to be neutral, and do not take it into consideration at all. Others, recognising this difficulty, assume for the purposes of the calculation that only a portion of the alumina is present. This method is adopted by the author, who takes two-thirds as the quantity. The phosphoric acid need not be considered, as practically all the phosphorus passes into the pig iron produced. The author then proceeds to show the method of calculation he adopts, and calculates the coke that is required in the blast-furnace reduction of a number of different kinds of iron ore. Thus in the case of a soft Upper Silesia brown iron ore containing—

	Per Cent.
Moisture	33.0
Silica	12.0
Alumina	8.0
Lime	1.0
Magnesia	0.5
Lead	0.6
Zinc	1.7
Carbonic anhydride	2.0
Iron	25.0
Manganese	1.5

about a quarter of a ton of limestone must be added as flux. Then for every 1000 units of ore, there is required in the blast-furnace—

	Units of Carbon.
In reducing 250 units of iron from the ferric oxide	57
For melting the slag	48
For melting the iron	35
In eliminating carbonic anhydride from the ore and limestone	38
In eliminating moisture	69
Total	247
Add 25 per cent. for radiation	62
	309

equivalent to 386 units of coke per 1000 of ore. Allowing 40 units for the carbon dissolved in the pig iron, the calculation shows about 1480 units of coke required for each 1000 units of pig iron made.

The author next calculates the amount of flux and coke required for an uncalcined clay ironstone containing 32 per cent. of iron and 25 of carbonic anhydride. Each 1000 units of ore necessitates the use as flux of 450 units of limestone, and the coke required for each ton of pig iron made he calculates to be 1·580 ton. His next case is that of cinder from the puddling furnace which, with 20 per cent. of silica, 53 of iron, and 8 of manganese, requires 790 units of limestone as flux for each 1000 units of cinder, and 1·410 ton of coke per ton of pig iron produced. For hammer scale, with 30 per cent. of silica, 50 of iron, and 1·5 of manganese, these quantities are respectively: for limestone, 1410 units; for coke, 1·820 ton. The residues from the calcination of pyrites, containing 10 per cent. of water, 60 of iron, 2 of silica, and 1 to 2 of lead, require 76 units of limestone as flux for 1000 units of ore charged, and 0·505 ton of coke for each ton of pig iron made. Similar calculations are made for calcined spathic ore, and for magnetite. The real cost of the ton of pig iron is deduced from these calculations, and in the case of the brown iron ore first referred to it is shown to be as follows:—

	s.	d.
Cost of the ore	18	7½
Cost of the limestone	1	6½
Cost of the coke	11	10
Wages	3	0
Power, and general costs	7	5
Total	42	5

For each ton of pig iron made, 3·72 tons of iron ore are assumed to have been charged into the blast-furnace. From this total cost must be subtracted the value of the by-products, such as the lead produced in the furnace, and the zinc sows and fume that form. On the other hand, however, the zinc causes so much trouble in the furnace that it probably does more harm than is made up for by the value of its products, besides which the loss of lead in the furnace treatment is so extremely variable that any advantage to be gained from it cannot be taken into account.

The Schalker Blast-Furnaces.—These are situated near Gelsenkirchen, Germany. They are five in number, of which three are in constant use, each being provided with either three or four Cowper

stoves. The blast is blown at a pressure of 11·8 to 17·7 inches. The three furnaces are from 66 to 72 feet in height, and from 9 feet 10 inches to 19 feet 8 inches in diameter. The outturn of pig iron is about 5000 to 5600 tons per month. About 30,000 slag bricks are made daily, a little more lime being added to the blast-furnace slag before moulding. A pipe foundry is in connection with the furnace.*

Anthracite Blast-Furnace Plant.—E. F. Dürre† describes the oldest anthracite blast-furnace plant in Pennsylvania. The use of anthracite in the place of coke is, the author observes, one of the most marked peculiarities of American metallurgy. The discovery of anthracite in America is much more recent than that of ordinary coal. It dates from about the year 1790, the discovery having been made by a hunter named Philip Ginter. He found the coal at a spot near what is now the town of Summit Hill, in the mountains of the Lehigh river. The first shipment of the fuel to Philadelphia took place about the year 1800, but it was years before the quantity raised was considerable. In 1834 the shipments on the Lehigh river amounted to 481,832 tons—now it is as much as 45 millions. The first blast-furnace in the United States in which anthracite was used as fuel was erected in 1833 at Pottsville, in Schuylkill county, Pennsylvania. The blast had very slight pressure, and the furnace was soon blown out. Another furnace was built by David Thomas of the Crane Works at Yniscedwin, Wales, for the Lehigh Coal and Navigation Company. David Thomas reached America in 1839, and at once began building. The furnace erected was 42 feet in height, and 12 feet in diameter at the boshes. The blast was worked by water power, and had a temperature of 320° C. The ore charge consisted of two-thirds brown iron ore from the vicinity, and one-third magnetite from New Jersey. The fuel was wholly anthracite. The best weekly outturn was 52 tons. This furnace was in blast until 1880, ordinary repairs excepted. A larger furnace was blown-in in 1842, and a still larger one in 1846; while, the market still increasing, two more furnaces were erected. In 1855 the Crane Ironworks passed to the management of David Thomas' son, who built the Thomas Ironworks, with six blast-furnaces, at Hoken-daqua. In 1867 the Crane Ironworks erected another blast-furnace of the dimensions: height, 60½ feet; diameter, 17 feet. The three oldest furnaces were subsequently replaced by two newer ones whose dimen-

* *Stahl und Eisen*, vol. xiii. p. 686.

† *Zeitschrift des Vereines deutscher Ingenieure*, vol. xxxviii. pp. 258-262.

sions were still larger, the height being increased to 75 feet. A furnace of this height now in blast, $17\frac{1}{2}$ feet wide at the boshes, with a bell 8 feet in diameter, is worked for foundry iron, yielding a metal containing:—

Silicon.	Phosphorus.	Sulphur.	Manganese.
2.5	0.75	0.15	0.5

The output is about 100 tons a day. The ore charge consists of about 70 per cent. of brown and red iron ore, and 30 per cent. of magnetite. The blast has a pressure of from 8 to 10 lbs. per square inch, and is heated in three stoves with hexagonal brickwork to a temperature of about 800° C.

A basic pig iron made in another furnace contains:—

Silicon.	Phosphorus.	Sulphur.	Manganese.
0.6	2.85	0.025	0.6

An acid Bessemer pig iron also produced has the average composition:—

Silicon.	Phosphorus.	Sulphur.	Manganese.
1.5	0.07	0.025	1.05

This is made with blast heated in pipe stoves to a temperature of 460° C.

The average quantity of fuel used per ton of pig iron made is 1.2 ton. The fuel now used is three parts anthracite, and one part coke from West Virginia.

The ores used are somewhat numerous. Of magnetites, that from Lake Champlain contains on an average 63.817 per cent. of iron and 1.064 of phosphorus, while others have the composition shown by the following analyses:—

No.	Fe.	Fe ₂ O ₃ .	FeO.	MgO.	CaO.	Al ₂ O ₃ .	SiO ₂ .	S.	P.
1.	57.1	...	...	1.15	5.18	...	7.78	...	1.29
2.	60.4	...	...	...	...	...	...	...	0.40
3.	59.5	...	...	...	...	...	...	...	1.50
4.	...	64.52		1.26	2.76	1.45	4.20	0.11	0.24
5.	41.7	...	...	4.03	5.36	1.53	12.43	0.07	0.04
6.	44.1	...	...	4.66	2.60	3.87	16.64	0.23	0.05

(1) Sterling Mine, Ogdenburgh; (2) Hibernia Mine, New Jersey; (3) Orchard Mine; (4) Mount Pleasant Mine; (5) Bittenbend; and (6) Gehman Mines, Pennsylvania. These two latter ores contain respectively 1.4 and 1.8 per cent. of manganese.

Other analyses are given of various red hæmatites smelted, and details are also tabulated showing the position of the anthracite blast-furnace industry in the United States.

Closed Charging Apparatus.—Charleville's * apparatus has been in use for more than eight years, and is adopted at thirteen blast-furnaces. Most of these have retained the gas-collecting cylinder, and all the gas is conducted away at the desired depth below the mouth by the lower edge of the cylinder. The reason for this procedure is the fear that in charging no gas would be drawn off, and therefore explosions might be caused. Experience has, however, shown that such fear is baseless, so that the collecting cylinder has been dispensed with, and the gas withdrawn immediately below the charging level. As the gas can thus furnish more heat to the charge before it leaves the body of the furnace, it would appear that an economy in fuel should result. Moreover, the same advantages must be attained as those produced by increasing the height of the furnace. In one furnace (Björneborg) it has been found possible to increase the burden, and 100 kilogrammes of pig iron are produced by the consumption of 47 hectolitres of coal—a result not previously attained. The iron is grey, and the blast has a temperature of 500° to 600° C.

Hot-Blast Stoves at the Neckingen Ironworks.—The hot-blast stoves at this new ironworks in Lorraine are modifications of the Cowper stove, with which, in general principle, they are in accord. The stove, however, instead of being filled in the usual way, has the bricks replaced by a number of tubes internally cylindrical but externally hexagonal in form. They are a little less than 6 inches wide in the clear, and about 1·2 inch thick at their thinnest portion. These pipes rest on a grill composed of fire-proof slabs 3·1 inches thick and 19·7 inches in height, which in turn rests on a walling of arches and pillars. Other details are given.†

Blowing Engines.—In the discussion ‡ on J. Kennedy's paper § on blowing engines, additional descriptions and illustrations are given of several of the engines used at different works. J. Morgan, jun., describes that erected in 1888 for the Cambria Iron Company of Johnstown, Pennsylvania. It has two horizontal steam cylinders 48 inches in diameter and 72-inch stroke, coupled at right angles on to the same shaft, on which is a 30-ton fly-wheel. The steam pressure

* *Wermländska Annaler ; Berg- und Hüttenmännische Zeitung*, vol. liii. p. 112.

† *Stahl und Eisen*, vol. xiii. p. 850.

‡ *Transactions of the American Institute of Mining Engineers*, Discussion (advance proof).

§ *Journal of the Iron and Steel Institute*, 1893, No. II. p. 437.

is 70 to 80 lbs. The air cylinders are 60 inches in diameter, with 72-inch stroke. The most novel feature is in the valves, both inlet and outlet valves being metallic slide valves of gridiron type and fan shape placed in the heads of the cylinders and worked mechanically. The valves show but little wear as they move when there is only a small pressure on them. Both valves can lift slightly in case of failure of the mechanism. The wear of the pistons in the horizontal cylinders is but slight.

These engines are also described, with the aid of illustrations of the valve and of the general arrangement, by J. C. Brookes, who also gives a number of indicator diagrams to show the automatic action of the valves. The horizontal type of engine is certainly to be preferred, and the lift valves will be replaced by a positively worked type on all high-speed air ends of blowing engines.

The necessity of careful attention to the steam valves of blowing engines is urged by D. Baker, who gives an instance in which the wrong setting of these valves caused much extra work to be thrown on to the engine, whereby it worked loose from its bed. In this case the exhaust valves were set to close when the piston was still 10 inches from the end of its travel, and the steam valves had a 1·16-inch lead. The high compressions first broke a crank and then worked the foundation bolts loose. By altering the valves to 1·16-inch lap this was remedied. A vulcanised mixture of asbestos and india-rubber has been found to make a serviceable material for the air valves.

P. Burdy * describes at some length the construction of compressed air machinery at Le Creusot. After reviewing the various types used and the chief features of construction of the various parts, an illustrated description is given of the blowing engines erected at Bességes and at Longwy.

Ironworks in Nova Scotia.—W. Stein † describes the new works of the New Glasgow Iron, Coal, and Railway Company at Ferrona, Nova Scotia. The plant was commenced in 1891, and was put in operation in September 1892. It consists of a railway system, iron ore mines, limestone quarries, ore washers, coal washing plant, coking plant, and blast-furnace plant. The stock house is of wood, with corrugated iron roof, 91 feet wide by 250 feet in length. The coke is brought here in

* *Bulletin de la Société de l'Industrie Minérale*, vol. vii. pp. 419-463, with six plates.

† *Transactions of the Mining Society of Nova Scotia*, vol. ii., pp. 75-82, with three plates.

charging waggons, two of which are placed on a flat truck worked by an endless rope. The ore, flux, and coke are taken from the stock house to the top of the blast-furnace by a double elevator placed in an iron tower. The furnace is 65 feet in height, with 15-foot boshes and 9½-foot crucible. There are eight tuyeres, and two cinder notches. The bell is worked by an air cylinder. The casting house is 50 by 135 feet. The furnace has two downcomers, one supplying the boilers and the other feeding three hot-blast stoves. These are of the three-pass Massick & Crooke type, 16½ feet internal diameter and 65 feet high. A chimney on the top of each stove is 4 feet in diameter and 35 feet high. Blast is supplied by two engines with air and steam cylinders of 84 and 36 inches in diameter respectively, and a stroke of 4 feet. The cold-blast main is 30 inches in diameter, and it supplies one stove whilst the others are being heated. The boiler plant consists of light tubular boilers designed to carry 100 lbs. pressure. Each boiler is 6 feet in diameter and 20 feet in length. The coal washing and coking plant is also described.

Early Iron Manufacture in Nova Scotia.—H. S. Poole* describes an early trial, made in Pictou county by the General Mining Association, to smelt the local ores. The furnace, which was pulled down in 1855, was probably about 40 feet in height, and had an incline leading to the top. Experiments were made in 1829 with limonite and red hæmatite, and also with clay ironstone nodules from the coal. The blast for the furnace was obtained from the foundry engine, which worked at 5 lbs. steam pressure with condensation, but a larger blowing engine was imported. The steam cylinder of this engine was used at the coal mines, but the air cylinder lay on the river bank until 1884, when it was broken up. It is said that some 50 tons of iron was made, but it was useless for foundry purposes, being a hard white iron. An analysis of this metal shows :—

Silicon.	Manganese.	Sulphur.	Phosphorus.	Combined Carbon.	Graphite.
0.409	0.504	1.238	0.788	1.295	0.668

An earlier attempt was made in Pictou county, according to Haliburton's history and other sources, extracts from which are given by the author. This trial was at Nictau, and seems to have met with some measure of success, but from several causes, political and otherwise, it was not carried on. In 1858 the Acadia Iron Company had built works

* *Transactions of the Mining Society of Nova Scotia*, vol. ii. pp. 144–151.

at Nictau, and exported some 744 tons of iron, and 1125 tons in the following year. One of the furnaces was 35 feet high, 9 feet in diameter at the boshes, and $4\frac{1}{2}$ at the throat. The second furnace was of the same diameter, and 3 feet higher. In 1874 a furnace at Clementsfort was 35 feet high, with $9\frac{1}{2}$ feet boshes.

II.—CHEMICAL COMPOSITION OF PIG IRON.

Analyses of German Spiegeleisen.—H. Wedding* gives the following analyses of spiegeleisen from the works of the Siegerländer Verein, Germany:—

No.	Mn.	P.	Cu.	S.	Si.	C.
1.	31.30	0.08	0.15	0.04	0.30	5.30
2.	20.75	0.07	0.12	trace	0.83	5.88
3.	11.80	0.05	0.19	0.01	0.18	4.04
4.	11.50	0.03	0.18	trace	0.26	5.99

The Composition of Swedish Pig Iron.—R. Volkmann † gives the following analyses of Swedish pig iron:—

	Grey.	Mottled.	White.	
	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Combined carbon	0.380	3.500	3.700	3.700
Graphitic carbon	3.610	0.980	0.000	0.330
Silicon	1.470	0.950	0.300	0.420
Manganese	1.780	5.000	0.650	4.500
Phosphorus	0.017	0.018	0.017	0.018
Sulphur	0.009	0.006	0.011	0.006

The Influence of Aluminium on Pig Iron.—A. Borsig ‡ describes a series of experiments made on the influence of aluminium on pig iron. The aluminium used was the commercial variety, containing from 92 to 98 per cent. of aluminium. The experiments consisted in melting pig iron (1) by itself; (2) with the addition of 0.5 per cent. of aluminium; (3) with the addition of 1 per cent. of aluminium; and (4) adding 2 per cent. of that metal. In each experiment 0.3 ton of the pig iron was

* *Stahl und Eisen*, vol. xiv. p. 65.

† *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xli. p. 656.

‡ *Stahl und Eisen*, vol. xiv. pp. 6-16, with twenty-five illustrations.

melted down in crucibles under charcoal, and these were removed from the furnace when the iron was melted, the metal skimmed, and the aluminium then added. After being well stirred in, the metal was poured. Analysis showed that only a small portion of the aluminium added remained in the iron; in the case of the grey pig iron 5.9 per cent.; in white pig iron 9.5 per cent.; and in mottled pig iron 9.4 per cent. The loss is therefore greatest in the case of the grey pig iron, and this difference must be due to difference in the degree of the oxidising influence to which the aluminium is exposed. In hollows in the cast metal, and on the surface of the metal when molten, a film of alumina was observed. That aluminium does not readily alloy with iron has been maintained by Keep, but that this is not the case is proved by the present manufacture of ferro-aluminium on a commercial scale.

The influence exerted by aluminium on the other elements present in pig iron, when added to the molten metal in a crucible, is seen from the following tables :—

Grey Pig Iron.

No. of Test.	Aluminium Added.	Aluminium Found.	Si.	Mn.	P.	Total Carbon.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
1. {	Per Cent. None. Original pig iron.	...	1.37	0.44	...	...
2. {	Per Cent. None. Pig iron remelted.	...	1.10	0.33	0.30	3.62
3.	0.5	0.029	1.18	0.32	0.32	3.62
4.	1.0	0.069	1.18	0.33	Not determined.	3.58
5.	2.0	0.100	1.05	0.25		3.75

Only traces of sulphur were present in the metal.

White Pig Iron.

No. of Test.	Aluminium Added.	Aluminium Found.	Si.	Mn.	P.	S.	Total Carbon.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
1. {	Per Cent. None. Original pig iron.	...	...	traces	...	0.255	...
2. {	Per Cent. None. Pig iron remelted.	...	0.25	...	0.425	0.078	3.04
3.	0.5	0.050	0.24	...	0.394	0.039	3.03
4.	1.0	0.112	0.25	...	0.425	0.036	3.02
5.	2.0	0.160	0.23	...	0.390	0.043	3.21

Another case is given in which a pig iron, containing 5.15 per cent. of manganese, was treated in this way, and the experiments generally show that aluminium prevents the loss of the manganese, silicon, and carbon when the metal is remelted. Any aluminium that is present in a pig iron must therefore be eliminated by oxidation before either of these three elements can be oxidised. Although such slight changes had apparently resulted in the chemical composition of the metal, its physical structure had been greatly changed, in proof of which the author gives photographic reproductions of twenty-three fractures of metal treated in this way. With reference to the action of aluminium in converting a portion of the combined carbon of the metal into graphitic carbon, the author shows that, in the case of the white pig iron, while the remelted metal without any addition of aluminium contained 3.04 per cent. of carbon, of which 0.05 per cent. was graphite, the percentage of graphite gradually increased until in test No. 5. In that case the total carbon was 3.21 per cent., the graphite being as much as 1.53 per cent., while in test No. 4 the graphite was 0.85 per cent. It was thus evident that the 0.112 per cent. of aluminium retained by the metal was equal in its action to about 1.45 per cent. of silicon; in test No. 5, the 0.16 of aluminium was equal in its action to about 1.5 per cent. of silicon. Analyses are given showing that when either aluminium or silicon is added to grey pig iron the relative percentage of graphite in the metal is not appreciably increased. Aluminium tends more than silicon to prevent the "hardening" action of water, and the fractures of white pig iron hardened after the addition of the 2 per cent. of aluminium show spots of grey iron, and the separation of graphite is always observable. It makes the cast metal, however, extremely sound and free from blow-holes, probably in part by preventing the metal from dissolving gas, and in part by decomposing any dissolved carbonic oxide. An increase in the percentage of aluminium makes the iron more and more thick fluid, and in the charges to which 2 per cent. of aluminium had been added, the metal had to be cast rapidly, and this, the author thinks, is due to the formation of films of alumina around the particles of the iron. The iron shrinks less after the addition of the aluminium than it did before. The action of the aluminium on the tensile strength of the metal appears to be somewhat irregular. The action on the resistance to transverse fracture is similar.

In the case of a mottled pig iron containing, after remelting—

Si.	Mn.	P.	S.	Graphite.	Combined Carbon.
1.61	4.35	0.20	traces	1.94	1.01

the additions of 0.5 per cent., 1.0 per cent., and 2 per cent. of aluminium to the metal resulted in 0.06, 0.085, and 0.156 per cent. being retained by the iron, which, on being then submitted to mechanical tests, gave the following results :—

Aluminium per Cent.	Transverse Strength. Tons per Square Inch.	Tensile Strength. Tons per Square Inch.
None	13.52	...
0.060	17.90	17.59
0.085	19.43	15.49
0.156	21.08	17.65

The metal bent much more before fracture, after the addition of the aluminium.

A grey pig iron containing, when remelted—

Si.	Mn.	P.	S.	Graphite.	Combined Carbon.
1.10	0.33	0.30	0.0	2.98	0.64

gave, after similar additions of aluminium, the results shown in the following table :—

Aluminium per Cent.	Transverse Strength. Tons per Square Inch.	Tensile Strength. Tons per Square Inch.
None	17.08	11.65
0.029	18.03	12.25
0.069	15.81	10.50
0.100	16.44	10.09

There was no appreciable change in the bending of the metal before fracture produced by either of these aluminium additions.

Another example given is that of a white pig iron which retained when remelted :—

Si.	Mn.	P.	S.	Graphite.	Combined Carbon.
0.25	traces	0.425	0.078	0.049	2.99

This when tested showed :—

Aluminium per Cent.	Transverse Strength. Tons per Square Inch.	Tensile Strength. Tons per Square Inch.
None.	10.41	...
0.050	...	...
0.112	15.17	...
0.160	12.95	8.51

This metal was too hard to turn, and similar tests were consequently impracticable to those made with the other irons, which were made on turned bars clamped in jaws. The white iron bent somewhat more in the transverse tests after the addition to it of aluminium. The author concludes by saying that what is really required is some method by which aluminium can be added to iron without the great waste of the metal which occurred in these experiments.

III.—BLAST-FURNACE SLAGS.

The Calculation of Blast-Furnace Charges.—J. L. Saint Dizier * describes a method of rapidly calculating blast-furnace charges, which is based on the replacement of all the other bases by lime, replacing these according to their respective molecular weights. Various equations are given, but the calculations differ but slightly from those of the other methods of calculation previously published.†

IV.—FOUNDRY PRACTICE.

Cupolas and their Linings.—H. Bolze ‡ observes that the most customary form of furnace for remelting pig iron is the cupola, though for large pieces of scrap, broken rolls, &c., the open-hearth is used, or in cases when it is desired to produce a metal of a marked degree of toughness. The author describes a form of cupola that he has frequently employed, and observes that cupolas are now nearly always of cylindrical section, differing mainly from each other merely in the method of the introduction of the blast, which again is directed most largely to diminution in the consumption of coke, just as if, the author observes, “the salvation of foundry practice was mainly dependent upon this.” Modern designers, too, appear to be attempting to make this simple form of furnace as complicated as they possibly can. The Krigar cupola is an important modification of the original form. In this type a fore-hearth is introduced between the furnace and the tap-hole, which admits of a large quantity of metal being collected and kept hot before being tapped—an important point in the case of large castings. In the

* *Scientific Quarterly*, June 1893.

† *Journal of the Iron and Steel Institute*, 1891, No. I. p. 369.

‡ *Zeitschrift des Vereines deutscher Ingenieure*, vol. xxxviii. pp. 263-265.

case of cupolas, which melt more than three tons in the hour, such a fore-hearth is always of advantage, even when large castings are not required, as the tapping operation can be more quietly performed. For cupolas with a smaller output, or making small castings, the author does not consider the Krigar furnace as being of practical value. Another important variation in cupola construction is that in which the products of combustion are withdrawn by the action of a steam jet. The air enters through a circular slit instead of through tuyeres, and as the outturn of such a cupola of large diameter is much smaller than in that of the usual form, in which blast under pressure is employed, this form of cupola becomes practically disadvantageous when the output is to exceed $2\frac{1}{2}$ tons in the hour. On the other hand, for small casts its use is advantageous, and it is then perhaps worthy of selection before any of the other forms of cupola.

Passing to cupola practice proper, the author observes that after the bottom has been closed and the cupola has been started, care should be taken not to use too little coke in starting up, as if a sufficient quantity is used the casts will be good from the very commencement, which would not otherwise be the case. The author takes 5 or 6 cwt. of coke for this purpose in the case of cupolas of 2 feet in diameter.

To form a thin-fluid slag from the sand adhering to the iron and from the ash of the coke, lime is added in quantities which usually average from 15 to 20 per cent. of the weight of the coke. This lime must be added with every charge of coke, that is to say, even when blowing-in. If this addition is not made, the first metal tapped will have taken up sulphur, &c., from the coke, and be bad. Too much lime does no harm, the author considers, except in making the slag somewhat more pasty. Too little lime causes sulphur to pass from the coke into the iron, and the slag will become so pasty that it will not run through the slag hole. After referring to the usual minor points in connection with cupola working, the author considers the ratio that should exist between the quantity of iron charged as compared with that of the coke used. For the 2-foot cupola that he takes as his standard, the author considers that a charge should consist of 441 lbs. of iron and 38 lbs. of coke. For cupolas of larger or smaller diameter this ratio would be different, and, of course, the quality of the coke has always to be taken into consideration. Modern cupola improvers usually assert that they are able to effect a great saving in the quantity of the coke used, some statements being that the quantity can be reduced to 4 per cent. of the iron melted, or to about the half of that which the author gives above. This is usually to

be done by a preheating of the blast, or by the arrangement of many rows of tuyeres, one above the other. That such a reduction can be effected, or at least partly so, the author does not doubt, but he not only sees no advantage in this, but actually considers that it is accompanied by disadvantages. He considers that the designers of such forms of cupola overlook the protective action of the coke excess in the chemical changes which take place in the cupola. As the iron passes downwards in the cupola it is gradually heated up to the melting point, and remains in this molten condition as drops of metal exposed to the chemical influences of the ascending air and gas currents. The free oxygen combines with some of the constituents of the metal; iron, manganese, and silicon are oxidised, and some of the carbon is also eliminated; while if too little lime has been added, sulphur passes into the iron. The iron consequently not only diminishes in weight, but also in quality, and this action begins from the moment when the iron begins to melt, and continues until it has passed downwards into the well. The shorter this distance is, and the more coke and its combustion products are present, the greater will be the protection afforded to the iron from the action of the oxygen of the blast. The author has experimented in this direction, and he finds that when the same amount of coke— $7\frac{1}{2}$ per cent.—was charged, a cupola with two rows of tuyeres gave a harder variety of iron, the melting zone being larger, than resulted when a cupola with a single row of tuyeres was employed. With 5 per cent. of coke this latter cupola gave cold metal, while the other still gave a metal which was sufficiently hot. The quality, however, was much worse, and the loss of metal had increased by 1.5 per cent. To obtain satisfactory results with a low coke consumption, it would be necessary to employ a pig iron containing more manganese and silicon than would otherwise be necessary, with the result that the saving effected in the case of the coke would be much more than absorbed by the loss involved by the use of the dearer metal. The author considers the use of less than 7 per cent. of coke to be disadvantageous.

Great care should be taken always to keep the tuyeres clear during the melting, as they are very readily choked by slag accumulations. For this reason the author prefers to use a few wide tuyeres, rather than a larger number of tuyeres of small sectional area, and it is necessary that the tuyeres should be readily accessible.

The rapidity with which the iron melts is largely dependent on the quantity and pressure of the blast, and this rapidity of fusion is of great importance in the cost of the process. The author, with a cupola

some 16½ feet in height from tap-hole to the charging door, and 2 feet in internal diameter, uses blast with a pressure of from 20 to 24 inches of water, the quantity of metal that can be tapped out being from 2½ to 3 tons per hour. The latter quantity is about the largest permissible, if small articles are to be made which can be cast from a ladle manipulated by hand. For producing the blast, a Roots blower is the type the author recommends, and he points out the necessity for the use of some instrument to determine the pressure of the blast to be used, of care in the arrangement of the cupola charges, and other matters.

The question of the cupola lining is dealt with less fully. The author considers the ordinary brick lining to be much too expensive. It is far cheaper, he says, to stamp in a sand lining, or a lining of clay material. This can readily be done by the use of a sheet iron cylinder placed within the cupola, and between which and the cupola itself this lining can be stamped in. Above the fusion zone, however, this lining is rapidly worn away, and bricks have to be used. Instead of these, the author employs castings of iron of high melting-point. These he finds last for a long time, and they form a very cheap lining. The author employs a mixture of kieselguhr and clay in lining the ladles, the kieselguhr being an extremely bad conductor of heat.

In a paper read before the Western Foundrymen's Association, Chicago,* E. A. Wheeler urged the value of chemical knowledge to the foundryman, and gave some useful hints on foundry practice.

The Centre-Blast Tuyere Cupola.—In a paper read before the Western Foundrymen's Association, T. D. West† gave the results of experiments with a cupola with central-blast. The idea was first adopted in a cupola 40 inches in inside diameter, and the results were so satisfactory that the plan was tried in a large cupola 68 inches in inside diameter, in connection with the outside tuyeres. By the alteration in construction not only is fuel saved, but wear of the lining of the cupola is also lessened.

Moulding Machines.—In a paper read before the Foundrymen's Association at Philadelphia, H. Tabor‡ pointed out that there are certain conditions which are necessary to the production of economical work from moulding machines. There should be a reasonable number

* December 20, 1893.

† *Iron Age*, vol. lii. pp. 749-750, with two illustrations.

‡ *Ibid.*, vol. lii. pp. 1071-1073.

of castings made from one pattern or set of patterns, and this number will depend on the class of castings, and the cost of moulding them by hand. The kind of casting to be made must be considered. Work that requires a three-part flask, and patterns with too many pick-out pieces are better left to the hand rammer. Moulding machines should not be introduced unless they can be given the same care that is given to machinery elsewhere.

Fluxes.—In a paper read before the Foundrymen's Association at Philadelphia, E. Kirk * discussed the use of fluxes in foundry work. The results obtained from the use of limestone in small quantities in a cupola are so uncertain that he did not consider that they justify a foundryman using it. In order to overcome the tendency to clog, it is advisable to use a large quantity of limestone as flux, the quantity required to produce a fluid slag varying from 25 to 100 lbs. per ton of iron melted. The effect of limestone in a cupola is not to improve the quality of the iron, but to prevent its deterioration in melting. Oyster shells are frequently used as a flux in place of limestone. When used in large quantities, they produce a fluid slag that keeps the cupola working free, and that flows freely from the slag-hole, carrying with it the refuse of melting that clogs a cupola.

Sulphur in Cast Iron.—In his presidential address before the South Staffordshire Institute of Iron and Steel Works Managers, James Roberts discussed the views expressed by W. I. Keep on sulphur in cast iron, and brought forward facts disagreeing very materially from the conclusions arrived at by that gentleman. He shows that a much less quantity than 0.5 per cent. of sulphur does act deleteriously on the pig iron and castings, the largest proportion employed in his experiments being 0.214 per cent. This certainly affected the quantity of the combined carbon to a very large degree, and affected the strength of the casting.

The Artistic Treatment of Cast Iron.—In discussing the artistic aspect of cast iron, W. R. Lethaby † points out that, although cast iron cannot be said to possess the beauty of bronze, it has been used with appreciation in many ways up to the beginning of this cen-

* *Iron Age*, vol. lii. pp. 647-648.

† "Arts and Crafts Essays," by members of the Arts and Crafts Exhibition Society, London, 1893, pp. 184-195.

ture. He cites the cases of the iron fire-backs still met with in Sussex and Kent, and the iron grave slabs in Frant Church, near Tunbridge. Iron railings are the most usual form of cast iron as an accessory to architecture. The original railing at St. Paul's, of Lamberhurst iron, is the finest of these. Even the sculptor has not refused cast iron. Pliny says that in Rhodes there was a statue of Hercules entirely of iron. In the palace of Prague there is a St. George, horsed and armed, the work of the fourteenth century. The qualities natural to iron which it has to offer for sculpture may best be appreciated by seeing the examples in the Museum of Practical Geology. From an examination of examples, the author arrives at the conclusion that for artistic purposes cast iron must be good, and must be carefully manipulated. The pattern of the design must have the ornament modelled, not carved, carving in wood being unfit to give the soft relief required by the nature of the mould and of the metal. Flat surfaces, like grate fronts, may be decorated with some intricacy if the relief is delicate. Objects in the round must have a simple and substantial bounding form, with but little ornament, and that only suggested. When possible, the surface should be left as a metal casting. It may, however, be entirely gilt. If painted, the colour should be neutral and grey.

PRODUCTION OF MALLEABLE IRON.

Native Iron Manufacture in Abyssinia.—J. T. Bent * notes that the methods of iron manufacture in Abyssinia are very similar to those all over Africa, and that the paraphernalia of an Abyssinian smith is precisely identical with that of the tribes to the south of the Zambesi, where, however, the Mashonaland native produces a better article. The blacksmith in Abyssinia is looked upon with mingled dread and superstition. He is supposed to be able to communicate his magic powers to others, and to be able to turn himself into a hyena in the same manner as in were-wolf stories.

* "The Sacred City of the Ethiopians," by J. T. Bent, 1893, p. 211.

FORGE AND MILL MACHINERY.

Forging by Hydraulic Pressure.—After briefly reviewing the history of forging by hydraulic pressure, R. H. Tweddell * gives the conditions necessary for ensuring success in the operation. The press must be proportioned to ensure the utmost rigidity; the crane power must be ample, and arranged so that weights up to 100 tons can be manipulated without skilled labour; and the details of the valves and pumping appliances must be as perfect as possible. These conditions are discussed, and the means by which they are met in various types of presses are described. Descriptions of presses made in this country are given.

A comparison is then drawn between the forging press and the steam hammer. As noise and waste of energy are convertible terms, the superiority of the press is evident. No power is wasted in shocks to the framing and foundations as in the hammer. Besides this, the press occupies much less head room, so that travelling cranes can be used overhead. More work can be turned out in a given time, and the press can also work through a greater range. In addition, there is the economy in the dies, of which a greater assortment can be used. Formerly it was impracticable to forge hollow marine shafts as now used, or to draw out gun tubes or hoops on the mandrel. A hard and fast line cannot be drawn between forging presses and stamping and welding machines. With regard to the machines, the advantage of a blow as against steady pressure is a subject which gives room for discussion, as, for instance, in making wheels. Calculations have often been made as to the relative sizes of forging machines and hammers, but these are considered to be of no value, since the effect of a sudden blow, which is over at once, is quite different to the continuous pressure of the hydraulic forging machine. Moreover, the full stroke of the hammer cannot be obtained until the work is reduced in size, whereas

* Paper read before the Institution of Civil Engineers, February 20, 1894.

the full power of the press is always available. Appendixes give detailed accounts of the presses referred to, a comparison by C. Davy of a press and a hammer doing nearly equivalent work, and an account of experiments by Coleman Sellars on the number of blows and the pressure required to deform test pieces to the same extent.

In the discussion on this paper further particulars were brought forward, and the steam hammer was defended by Messrs. Moir and Ellis.

A detailed description, illustrated by means of eight drawings, has been published * of the Breur-Schumacher 1200-ton hydraulic forging press, constructed by Greenwood & Batley, of Leeds.

Universal Rolling Mill.—The universal mill erected at the Central Iron Works, Harrisburg, Pennsylvania, has 25-inch horizontal rolls and 16-inch vertical rolls, driven by a pair of 30 by 60-inch engines. The spur gearing driving the vertical rolls is placed within the housings, which are of exceptional weight. The screws of the horizontal rolls are operated by a rack and pinion through hydraulic cylinders, while the vertical rolls are operated by hand, the gearing on both sides being coupled. The maximum width which the train is capable of rolling is 42 inches. The roll tables are each 50 feet in length, the cooling table having a length of 80 feet. The plate is moved sideways from the cooling table by a chain rig, and a turning gear is interposed between it and the shearing table, so that both sides of the plate can be inspected. A hydraulic shear is used. The whole of the train, engines, and shipping department is controlled by a Morgan electric travelling crane with a 65-foot span, a smaller electric crane traversing the lower end of the building, and handling the slabs. Near this are two groups of two Siemens reheating furnaces, the doors of which are operated by hydraulic power, an electric travelling charging machine being also employed. Gas is supplied to the works by a battery of 10 Wellman gas producers, with 2 in reserve. The present capacity of the plant is about one hundred tons a day.†

The Turk System of Rolling.—This system is stated ‡ to differ from those in ordinary use, in that oval as well as rectangular bars can be automatically rolled and passed from one stand to the other of a train of rolls, the velocities of rotation of the rolls in the different stands

* *Engineering*, vol. lvii. pp. 241-242.

† *Iron Age*, vol. li. p. 548.

‡ *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xli. p. 591.

increasing in correspondence with the diminution in the diameter of the rod during the various stages of the rolling. The arrangement is purely automatic, no boys being required to handle the rod from the moment it enters the first stand of the roll train to that at which it leaves the train in its finished state.

A wire mill, partly on this system, has been erected at Thörl, in Styria, and this was put into work for the first time in November 1893. The results gave complete satisfaction, the work proceeding completely automatically, and wire of 0·18 inch diameter being made with facility.

Sheet-Mill Progress.—A. Beard * traces the recent progress in the construction of sheet-mill machinery. Unlike other branches of the iron and steel industry, there has been no record of radical or noticeable changes in the method of rolling iron and steel sheets until recent years. In the manufacture of bars, structural shapes and plates, the three-high, universal or Belgian and reversible mills have almost entirely taken the place of old style two-high rolls, but no one has to this date been intrepid enough to spend any very large amount of time or money in an attempt to revolutionise the old established process of making light sheets. Many improvements have been made in the manner of producing a high finish, and in a marked degree the quantity produced has been materially increased in mills devoted to the manufacture of sheets of ordinary finish, but so far as the initial process is concerned the sheet rolling industry occupies nearly the same position which it did fifty years ago. The inventions of Bessemer, Siemens, and others have assisted progress in sheet-mill practice, and have provided means in the shape of steel billets and sheet bars for the production of sheets of first-class quality at about the same cost for which common sheets were formerly produced. Sheet-mill managers have, however, combined their ideas with those of machinists and foundrymen, and as a result remarkable changes have been made in the construction of machinery.

In reviewing briefly the causes leading to these changes, the author discusses the English and American practice, illustrating his remarks by drawings of an English sheet mill with 20-inch rolls and housings weighing 11,000 lbs.

In American practice all light sheets are box annealed, being placed on cast iron carriers upon which the sheets are piled, and then covered with a cast or wrought iron lid, made air-tight by piling sand around the bottom. This carrier and box are then drawn into the annealing fur-

* *Iron Age*, vol. lii. pp. 840-843, 884-886, with ten illustrations.

nace and heat applied. By using this method, scale is not raised on the sheets—they are smooth, flat, and of even colour. In the matter of utilisation of waste heat, and the employment of power, great care is taken in English practice.

The main object of American sheet-mill men appears to have been to produce the largest quantity possible, and so construct the machinery that breakages become exceptions instead of the rule. The author gives drawings of an American sheet-mill plant, which shows many points of economy. Furnaces are all set near to the railway coal line, so that coal is unloaded directly into the bins at the sides of the furnaces. Under the coal bin shoots a narrow gauge line is laid, to convey sheet bars from the bar shears to the pair of furnaces. The large and small engines are placed near together, so that only one man is needed to attend them. The small engine drives two pairs of shears, runs the machinery to raise the annealing boxes, and also runs the roll lathe. The annealing furnaces are near to the shears, and no material has to be handled twice. The process is progressive from the billet furnace to the warehouse. All that has to be brought back is scrap from the sheet shears to the scrap furnace. A plant of this description would turn out 35 to 40 tons per day of sheets, from No. 18 to 30 gauge, and various widths from 20 to 36 inches.

With the increase in weight of sheet-mill machinery, designs have been improved. This is shown by the drawings, given by the author, of sheet-mill housings of Booth design 1893, for 24-inch rolls, weight 23,000 lbs.; of Lewis design 1893, for 24-inch rolls, weight 19,500 lbs.; of Leechburg design, for 24-inch rolls, weight 21,000 lbs.; and of Garrison design, weight 21,000 lbs.

In conclusion, the author describes the method of reworking the scrap or trimmings from the sides and ends of sheet packs, and refers to the continuous mill, invented by W. Garrett, which has not yet been successfully used on a large scale.

Steam Economy in Rolling Mill Engines.—R. J. Worth * calls attention to the great waste of steam in even recently built rolling mill engines. This is due either to bad design or to bad condition, the latter factor being of great importance in the smaller engines, which are not so carefully looked after as the larger engines. Such engines often use up to 690 lbs. of steam per horse-power per hour, when they should only use 40 to 50 lbs. As far as the design is concerned, the principal causes

* Paper read before the Cleveland Institution of Engineers, February 19, 1894.

of loss are disproportion of size to the work to be done, too low steam-pressure, and too little expansion. Too small an engine is bad, as it does not enable expansion to be used ; but still greater waste of steam is caused by having engines that are too large, especially if they are non-condensing. Very little is known of the amount of power required to roll iron or steel. Tests are not easily made, as with fly-wheel engines much power is taken from the wheel, so that the indicator diagrams do not show all the work used, and with reversing engines the diagrams differ at almost every stroke. Tabular statements of the power used at various mills are given, and it is concluded that 100 tons per shift can be rolled with about 1000 horse-power, and is not necessarily much more with reversing than with continuously running engines. The engine must be able to do the heaviest work required, and to stand the strain without continual repairing. The author then considers in some detail mills originally put up for iron and now used for steel, steel mills with uneconomical engines, and entirely new mills. Some discussion ensued in which triple-expansion, steam-pressure, and other features were touched upon.

The Eskbank Ironworks, New South Wales.—The first plate and sheet mill erected in the Australasian colonies has recently been opened * at the Eskbank Ironworks in New South Wales. These works, which were founded about seventeen years ago, cover 10 acres of ground. Fireclay and moulders loam are obtained close to the works, as also is the coal, which is brought straight to the furnaces from the adit. The seam is the Lithgow seam, 10 feet thick, of which the lower 6 feet is worked. There is an 18-inch bar mill driven by a 65 horse-power horizontal engine, and served by four furnaces, each capable of heating five tons per shift. A 2-ton steam-hammer is used for piling, and there are two puddling-furnaces and a scrap-furnace adjacent. Another 18-inch mill is driven by a 45 horse-power engine, and there is also a 14-inch bar mill with a 30 horse-power engine. The plate and sheet mill is a 42-inch mill with three furnaces ; it is driven by an engine of 175 horse-power. The rolls are respectively 4 feet 10 inches and 5 feet 4 inches wide. The galvanising works can make corrugated sheets up to 12 feet in length.

* *Industries and Iron*, vol. xvi. p. 467.

PRODUCTION OF STEEL.

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I.—THE CARBURISATION OF MALLEABLE IRON.

Dannemora Crucible Steel.—R. Volkmann * observes that the Dannemora Company lay down special rules for the treatment of their steel. Thus steel with from 1·2 to 1·6 per cent. of carbon may only be heated to a bright red, while steel with less carbon must not be heated to a temperature exceeding a yellow heat. Higher temperatures destroy the quality of the steel, which must then be remelted before being used. The Dannemora steel is stated to be capable of being welded with a percentage of carbon as high as 1·2. The temperature at which the metal is to be hardened must be kept low, and for steel with 1 per cent. or less of carbon, a red-heat should be employed. A higher temperature does not improve the degree of hardness, but on the other hand it lowers the elasticity and increases the tendency to fracture and to crack. In every case, however, the steel after mechanical treatment must be allowed to cool, and only hardened after being again reheated. The Dannemora crucible steel is peculiarly adapted for the manufacture of medical instruments and of pianoforte wire.

Swedish Tungsten Steel.—R. Volkmann * observes that, at the recent Chicago Exhibition, the Oesterby Company of Sweden exhibited a tungsten steel containing from 1·0 to 1·4 per cent. of carbon, and

* *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xli. p. 655.

† *Ibid.*, vol. xli. p. 655.

from 2·0 to 8·0 of tungsten. This steel cannot be welded, and must be worked with the very greatest precautions.

The Cementation of Iron.—J. Garnier * describes an experiment by the aid of which he endeavoured to ascertain whether the present slow method of cementation could not be greatly improved by the use of a current of electricity. To ascertain this he placed two iron bars in a fireclay tube, their ends being at a distance from each other of 0·4 inch. Between them he placed charcoal, and then heating the tube to a temperature of from 900° to 1000° C., he passed a current of 55 ampères and 2·5 volts through the rods. At the end of three hours it was found that the positive pole remained practically unchanged, whilst the negative pole had been cemented to a considerable depth. The iron bar originally contained only 0·001 per cent. of carbon.

II.—THE OPEN-HEARTH PROCESS. •

The Open-Hearth Process in the United States.—A. Ledebur † discusses H. H. Campbell's paper ‡ on the open-hearth process. He points out that the maximum size of the open-hearth is solely dependent on local circumstances. A 500-ton furnace is not an impossibility. It is the manipulation of the metal after it has been melted that affords the greatest difficulty, as even a 100-ton furnace would require enormous casting and rolling appliances. The shape of the furnace is next considered, and the question of the elimination of the phosphorus and sulphur is passed in review.

In the discussion on the paper by H. H. Campbell on the open-hearth process, G. W. Goetz § refers briefly to the differences in the American, English, and German practice, and also to the Bessemer process. In America the duplex system is not economical as a rule. Some experiments were made by him with this method in a 15-ton furnace charged with the metal from three blows of an acid converter. Good dephosphorisation was attained by leaving the metal of the first heat hard and the succeeding ones somewhat soft as long as sufficient basic additions were present, but the subsequent dephosphorisation was

* *Comptes Rendus de l'Académie des Sciences*, vol. cxvi. p. 1449.

† *Stahl und Eisen*, vol. xiii. pp. 869–875.

‡ *Journal of the Iron and Steel Institute*, 1893, No. II. p. 457.

§ *Transactions of the American Institute of Mining Engineers* (advance proof.) 1894.—i. 2 M

slow. Many consecutive duplex heats are destructive of the bottom, especially during the reaction on admixture. The time gained is more than off-set by the oxidation during the melting stage. After referring to the duplex process at Witkowitz, as described by P. Kupelwieser,* a description of a more recent form of stationary furnace is given. This is a 20-ton furnace, designed by S. T. Wellman, with high and straight roof, and with pockets in front of the regenerating chambers, which are placed under the charging floor instead of under the furnace. The effect of the hydrocarbons in the gas on the luminosity of the flame, and its consequent radiating power, is then dealt with. It is bad practice to burn deposited carbon out of the chequer work during the reversal, as deposition from natural or rich gas can be prevented by admitting the requisite amount of steam. Ultimately the same amount of heat is produced by burning gas with a luminous or a non-luminous flame, but the radiating power of the former enables the heat to be utilised more advantageously in many instances. The solution of the problem depends, to a large extent, on the proper disposition of the air and gas ports. Water gas enables larger proportions of pig iron to be used, but sufficient can be employed in the present basic practice without the use of the richer gas. More sulphur is absorbed from the gas when the whole charge is melted down at once than when successive additions are used. The elimination of sulphur in the process is very uncertain, but the effect of high manganese is to be noted.

H. D. Hibbard remarks on the importance of separately governing the draught through the gas and air chambers. The value of tar in the gas is apparently underrated. By placing the producers near the furnaces, the air regenerators may be made larger and the gas regenerators smaller. In this way some of the sensible heat of the producer gas may be saved. The pyrometer seems to be of no use, as the bath, slag, and furnace all have different temperatures. The joint in basic furnaces between the bottom and the walls will stand if it is vertical and free from pressure. In discussing the composition of the slag it has to be remembered that when ore is used the silicon in the acid process is constantly reducing its effect, whilst its action in the basic process is constant, so that much less is needed. A pig iron free from sand in the basic furnace favours the production of low sulphur steel, as higher combined silicon would be permissible in the iron, which generally occurs with lower sulphur. In considering the variable factors in the process, the author had criticised one of his papers, and objected

* *Journal of the Iron and Steel Institute*, 1893, No. II. p. 6.

to the hearth as unimportant, but as it does not remain passive, it must be taken into account. The loss in melting is nearly a function of the time, and the furnaces from which the data are drawn melt quickly, with unusually mild oxidising conditions.

A. Hennin discusses the alterations of the hydrocarbons, and shows that some of the higher members are present in the gas and affect its luminosity and heating power.

H. Wedding mentions the Darby recarburising process and the modification of it in use at Dudelingen. The result is good, and although only used for basic steel, there is no reason why it should not work with acid steel.

H. M. Howe expects a certain economy of heat in the tilting furnace, as the slag can be readily removed, whereby the metal is more directly exposed to the heat without the intervention of a bad conductor. Slight differences of temperature can be seen, as in the case of the recalcrescence point, where the rise often does not exceed 10°C .

In reply, H. H. Campbell considers that although the luminosity of the flame may have much effect on the heating power, yet the experiments show that washed gas did good work. Other points, especially the determination of temperature, are also shortly dealt with.

The Open-Hearth Furnace.—F. Toldt* publishes an elaborate monograph on the open-hearth furnace, which forms a continuation of the calorimetric studies made by the author and Professor von Jüptner.† Open-hearth designs, the author observes, are usually copied from existing furnaces, or are built without any definite attempt at a systematic scientific principle. If it is possible to control the working of a gas producer, why not do the same for an open-hearth? If all that happens in the working of the open-hearth is correctly ascertained and understood, would it not be possible to construct such a furnace on lines that will best meet these requirements? If a number of drawings of open-hearth furnaces are examined, it will be found that in some cases the air and gas ports are large, in others relatively small; that sometimes the gas regenerators are of equal size, while in others the air regenerator may be the larger, and so on in infinite variation. Which of these is the right one? It is this question that the author considers. The author cites statements that have been made from time to time as to the relative

* *Berg- und Hüttenmännisches Jahrbuch der k. k. Bergakademien*, vol. xli. pp. 289-448.

† *Journal of the Iron and Steel Institute*, 1890, No. II. p. 707.

size of the hearths in connection with the duration of the melting process and the material melted, and other points, observing that although this information, derived as it is from actual practice, is of interest, yet using it as a basis, furnaces might be constructed which would differ enormously from each other. Such statements are consequently of little general importance. He therefore attempts to give a table showing the velocities of the air and gas at the various points of an open-hearth. If the quantities and temperature of the gas, with the volume and temperature of the air for the combustion are known, it is evident that it would be possible to calculate the necessary section at any point of the furnace. The author calculates the velocities of the gases from the dimensions of a furnace, and from experimental results.

He quotes analyses published by F. Kraus, of the producer gas made at Saint-Gobain from a coal containing—

Carbon.	Hydrogen.	Oxygen.	Nitrogen.
84.380	6.168	6.898	2.544

From every 100 lbs. of this coal 602.17 lbs. of gas was made, 155.9 lbs. of which was carbonic oxide, 8.0 lbs. marsh gas, and 3.7 lbs. hydrogen, the remainder being incombustible. The calories yielded by the combustion of this gas are considered, this being taken as an example of the method of calculating the quantities of gas produced, with the heat absorbed in their production, and evolved in their combustion. The next illustration given is one of the working off of a furnace charge in the case of a heating furnace, which in the 24 hours made 5.6 tons of finished product from 9 tons of metal charged. The loss of heat in the stack, by radiation, by absorption by the iron, and by the furnace, is considered at much length. The calorific intensity is also discussed, and the author then passes to a consideration of gas producers generally.

Examples are given of a producer gas made from coke and of another from coal; and it is shown that in the former the maximum attainable temperature was 1710° C., and in the case of the latter 1728° C. The question of the open-hearth is considered under ten heads:—On producers in general; on the gas leads from the producers to the valves; the valves; the channels from the valves to the regenerator chambers; the regenerators; the gas and air escape ports from the regenerators; the hearth; the calculation of the dimensions of the open-hearth; calculation of certain special furnaces on the basis of available data; and, finally, general conclusions. Each of these heads is considered at considerable length.

The author passes in review various published statements by Uhland, Schmidhammer, Ledebur, and others as to producers in general, and also as to special forms of producers, including the differences which exist between producers working with a natural draught and those in which a forced blast is used. Kleemann, he shows, divided even in his early producer the period of the dry distillation of the coal from that of the actual gasification; and an illustration is given of a producer resembling at first sight a Siemens producer, but which has a space for the gasification of the coal, another for the dry distillation, and a third for drying the coal preliminarily. The method of using this producer is described, and the results of its working are shown. The dry distillation of coal is then dealt with. At 550° to 600° C. gases are evolved which burn with a strongly luminous flame, steam and tar form, the coal intumesces, and coke is produced. In the second period, in which the temperature rises to a bright red, the coke itself gives off gas, diminishing at the same time in volume. The gas so given off from the coke forms almost a third part of the total gas volume. These coke gases are not accompanied by the formation of tar, and burn with a flame which is only slightly luminous. The coke which remains at the end of the first period is apparently a mixture of various solid carbon compounds, whose mean composition approximates to the formula $C_{15}H_4O$. This product is decomposed again in the second period of higher temperature, but even at a white heat the elimination of oxygen, hydrogen, and nitrogen is not complete.

The questions of the use of steam in conjunction with air in the producer, and as to whether the producer should be worked hot or cold, are also considered. It is shown that the utilisation of the fuel in producers into which steam is passed, is more complete than in the case when no steam is passed into the producer, provided that the gases are cooled before they are burnt. It is, however, only in special cases that this cooling down of the gas is to be recommended.

As to the question of working the producer hot or cold, the author quotes from various publications on this subject, and refers to the regeneration of blast-furnace gases. He shows that there is much to be said on both sides, and then passes to the consideration of the permissible thickness of the layer of fuel in a Siemens producer. He quotes the remarks of Stöckmann and Ledebur, and others, on this point, the size of the fire-bar space being also considered. The next matter passed in review is the quantity of air to be passed through the producers in special cases, and he considers that Ledebur's statements as

to the grate area are worthy of credence. Various forms of producers are passed in review, and the gas-leads to the valves are then discussed. These should be kept perfectly dry. Where possible, the gas should rise from the producer through a vertical pipe, which then acts as a condenser, and allows the tar to condense and run back, thus keeping the valves clear. Various points connected with the velocity of the gases, the placing of man-holes at intervals, and arrangements for taking samples, are considered. Several forms of valves are discussed, and then the dimensions which it is necessary to give the channels leading from the valves to the regenerator chambers are considered. On this point he has been able to find no literary references. He holds that the channels should have the same size at the valves as that of the incoming duct. It is desirable that the air used in the combustion of the gas should have a higher temperature when it reaches the furnace, than the gas which is to be burnt. But as the air, where it enters at the valves, is of the ordinary external temperature, it will be colder when it reaches the regenerators than the gas. It must, therefore, be much more strongly heated in the regenerators than is necessary in the case of the gas, and this can only be effected by diminishing its velocity, and so causing it to remain for a longer time in the regenerators.

The regenerator chambers form the next stage in the author's classification, and in considering these, former literature is fully dealt with. It is held that a low velocity in the regenerator is very desirable. The author deals with the question of the area of the heating surfaces in the regenerators for the air heated, and the product of the furnace to which they are attached. Calculation will always show that it is far better to work at as low a temperature as possible rather than at a high one. Calculations are given for three typical cases as to the velocity of the air and gas in the regenerators. He suggests various modifications in the arrangements of hot-blast stoves, and illustrates these by a sketch. He then passes to a consideration of the influence of the size of the regenerators, whether too large or too small, and he shows that in the upper parts of the regenerators a temperature in excess of 1200°C . is attained. As a consequence, no ironwork is possible in these upper portions, but at the bottom it is different, and this part might well be made of malleable iron. He suggests the use of this material, maintaining that it will more readily take up the lost portions of the heat from the escaping gases than will brickwork, and inversely that, when the direction of the valves is changed, the heat will be given up again more readily and with greater rapidity.

The gas and air ports are then discussed. Employing the term "burner" for the whole of these entrance ports in a furnace, the author propounds the question—"Why should not this burner be removable?" This he thinks quite feasible. It would be well too, he says, if the ports could be closed when not in actual use, as leaving them open leads to loss of heat. The ports must be so arranged that an intimate admixture may be obtained between the incoming currents of air and gas, but this is not a difficult question to decide. Perhaps the most important matter to bear in mind is that the incoming gas shall not come into contact with the brickwork of the furnace. A burner in which the gas is shielded by air on all sides, above and below, is especially to be recommended, as not only will the air protect the furnace walls, but it will lead to a more intimate admixture of air and gas. To ensure perfect combustion, the temperature in the combustion chamber should be high, the contact of air and gas should be as complete as possible, and the dilution by incombustible gases should be as little as is practicable. The use of separate combustion chambers is referred to.

The next portion of the monograph refers to the hearth of the furnace itself. The material of which the hearth should be constructed is not considered, as the subject is one of general knowledge. The deeper the bath of metal, the slighter is the possible oxidising action of the gases and also the transfer of heat. The process is consequently slower, and the amount of fuel consumed proportionately increased. The usual ratio between the width and length of the hearth is 2 : 3, but the ratio 3 : 4 is also known, and circular furnaces have also been built. If the furnace is too short, the flame will pass through into the regenerators and destroy them, while if the furnace is too long, the flame will not heat sufficiently that portion of the charge which is near the far end of the furnace. The next point considered is the calculation of the furnace dimensions. Certain special cases are taken, and dealt with in detail. These are three in number, and their conditions are very dissimilar, the compositions of the fuel and gases being so chosen that in the one case the calculation is easy, while in the other two difficulties are introduced which have to be met in order to arrive at workable figures. These calculations cover twenty-eight pages of the monograph. The fuel is considered, and also the temperatures at the various parts of the open-hearths, the velocities, the times, &c., together with the cubic capacity of the regenerator chambers, the sectional areas of the various parts of the furnace, and other points connected with this question.

The Schonwälder Open-Hearth.—This furnace has already been referred to in previous abstracts.* Since the 5th of April of last year † it has been continuously at work, and, holidays and Sundays being subtracted, made in 219 days, down to December 22, 852 charges, with a total yield of 11,425 tons of ingots. From April until August the charge consisted of from 25 to 30 per cent. of pig iron, and from 70 to 75 of scrap, while from September 1 onwards, the charge was half and half of each. Four charges were worked off each day, and the furnace is still in excellent condition. The valves have done most excellent service in the prevention of wear and tear. A second furnace is giving equally good results. Between May 18 and December 22 it had worked off 704 charges in 178 working days, about 4 charges a day, as in the other furnace. The total output of ingots was 9439 tons, the composition of the charge being identically the same as that employed in the case of the first furnace.

Gas-Reversing Valve for Steel Furnaces.—J. Barr ‡ describes a modification of Siemens' gas-reversing valve for steel furnaces. In the ordinary four-way valve the tongue is oval, and is hung on a central spindle. It was found that the tongue could be shaped by hand at less cost than by machine work. Owing to the heat, and to the burning of any escape of gas, this valve speedily warps, so the author designed a valve with a square tongue and side doors on the valve body. In the first valve, the tongue was made with end discs, but condensation of soot and slight warping soon caused it to stick. Ledges were then cast on the body and on the end doors on which the edges of the tongue bear. The edges are machined, and ample play is left. In one valve the edges of the door were flat when bearing on the ledges. In a second valve the edges are knife-shaped, to cut into any deposit so as to make a gas-tight joint. The first of these has been in constant use for four months.

Washing Pig Iron.—H. Wedding § states that the Krupp dephosphorisation process, known in the United States as "washing," is still in use at the Cambria Works. The dephosphorised or washed metal prepared for the three rotating open-hearths has the composition :—

Carbon.	Silicon.	Phosphorus.	Sulphur.	Manganese.
3·370	0·012	0·007	0·030	0·000

* *Journal of the Iron and Steel Institute*, 1892, No. II. p. 453; 1893, No. I. p. 327.

† *Stahl und Eisen*, vol. xiv. p. 48.

‡ Paper read before the West of Scotland Iron and Steel Institute, December 7, 1893.

§ *Stahl und Eisen*, vol. xiii. p. 1030.

The Bethlehem Steelworks.—In addition to blast-furnaces, puddling-furnaces, a Bessemer plant, foundry, rolling-mills, &c., the armour-plate and ordnance division of the Bethlehem Works * possesses four open-hearths, of the respective capacities of 10, 20, 40, and 40 tons. A casting 110 tons in weight is thus possible. In the moulds the molten steel is subjected to a pressure of 7000 tons by the Whitworth method. There are two forging presses, one of 2000 tons and the other of 5000 tons, both served by overhead cranes. Two heating furnaces are associated with these presses. The water for the pressure cylinders of the presses is provided by two Whitworth pumps, while air compressors are used in working the cranes. In the armour-plate shop is a steam hammer of 125 tons capacity. This hammer is described in detail, with the aid of four illustrations. In making the foundation for this hammer, a series of long poles were first driven into the ground, on which a series of layers of plank were laid. These layers of planks were separated from each other by sawdust. Then came a series of cast-iron slabs, followed by another thickness of wood, on which cork was nailed; then steel bars surmounted by baulks of oak; next another set of cast-iron slabs with a layer of planks and cork, and finally six layers of cast-iron ingots. On this the 30-ton anvil was placed, the total weight of the whole foundation considerably exceeding 2000 tons. A 14,000-ton press is nearing its completion. Engines of 16,000 horse-power are to work the pumps, and the hydraulic pressure is to amount to about 70,000 lbs. per square inch.

The Desulphurisation of Steel.—E. H. Saniter† has recently given later particulars of his process of desulphurising iron and steel. Ladle desulphurisation is dealt with by a number of analyses of basic iron and of hæmatite iron before and after treatment. In the basic open-hearth almost any sulphurous material may be used, but the slag made should contain about 50 per cent. of lime, and should be formed as quickly as possible. To this slag, from 45 to 75 per cent. of 70 per cent. calcium chloride is added per ton. A number of analyses of the iron used and of the steel produced by the basic process is given, in which the sulphur has been removed, about 20,000 tons having been treated. Steel containing 0·2 to 0·25 per cent. of manganese has been made and rolled without a blemish. Some of the steel made by this process from white

* *Stahl und Eisen*, vol. xiii. pp. 679–682, four illustrations.

† Paper read before the West of Scotland Iron and Steel Institute. A copy of this paper has been presented by the author to the Library of the Iron and Steel Institute.

hematite pig iron containing 0·06 of sulphur, is equal to Swedish bar, and is used for high-class cutlery. In the basic converter the slag should also contain about 50 per cent. of lime, and about 40 lbs. of calcium chloride is added, after which the metal is blown in the usual manner. The results are good provided that there is sufficient phosphorus to give the necessary heat.

Amongst other contributions to the discussion, Mr. Retchford gave an account of some experiments in ladle desulphurisation at Glengarnock. These were not successful, but this is ascribed to the non-removal of the sulphurous slag before the metal was transferred to the converter. The necessity of skimming off this slag is insisted upon as of great importance.

III.—THE BESSEMER PROCESS.

The Bessemer Process in Sweden.—In the discussion* on Professor R. Åkerman's† paper on the Bessemer process as conducted in Sweden, J. Hartshorne gives his experience as confirming the statement that the ingots are better when the metal is cast at lower temperatures, and the range of permissible temperature is smaller as the metal becomes softer. Some details are given of the practice at Pottstown, where a rough estimate of the heat is made from the amount of skull left in the ladle. When the metal is cast at too high a temperature, the blooms and billets show surface imperfections, roll badly, and contain many blow-holes near the surface. Mechanical tests confirm these observations, and show more brittle metal. The same rules as to temperature obtain with open-hearth steel, but the range of temperature is greater, as less gas is contained in the metal. The fluidity of the slag is a cause of the slight tendency of Swedish metal to red shortness, and the same holds in basic blows, where but little more manganese is now added than in the acid process. The thinness of the slag also reduces the loss of metal, as it carries away less in the form of shot. The Caspersson ladle is doubtless valuable in Swedish works with small charges, but the same effects may be obtained by the use of shallow, dish-shaped ladles, in which the metal is allowed to rest for a few minutes.

W. F. Durfee remarks that the results of the use of a large amount

* *Transactions of the American Institute of Mining Engineers* (advance proof).

† *Journal of the Iron and Steel Institute*, 1893, No. II. p. 470.

of blast at a low pressure confirms his deductions from some experimental work at Wyandotte, and his views advanced nearly thirty years ago.

H. H. Campbell, by means of calculations based on the several elements given in one of the author's tables, shows that the effect of the oxygen in the slag is much less than stated, and that the blast is practically the only source of the oxygen. In the open-hearth process it is of course different, as the metal is covered by the slag, and this shows that it is time for the quantitative history in the Bessemer process to be written.

The observations on the relation between the temperature of the metal and its behaviour during casting are a valuable record of Swedish practice, but this relation is not uniform in different works. In some cases the metal is always blown very hot, so as to keep a large percentage of silicon in the bath. As a rule, however, in America, hot metal gives bad results in the rolling mill.

J. L. Sebenius describes the method he employs to remove blow-holes from ingots by centrifugal force, without any additions, such as of silicon or aluminium, which he has not found to be perfectly satisfactory. The machine consists of a vertical shaft with radial arms, to the end of which steel cages are pivoted, so as to hang vertically when at rest, or to fly out to a horizontal position when the shaft is revolved. The ingot moulds are supported in these cages, and are filled simultaneously, so as to save time and to keep the metal thoroughly fluid. As soon as the moulds are filled, the machine is turned at about 120 revolutions per minute, and this is maintained until the ingots have solidified. Two of these appliances are at work in Sweden, and others are being built elsewhere. For ingots of about 15 inches square, solidification takes about ten minutes, and for every ton treated, about 5 to 6 horse-power is required. Bessemer or open-hearth steel treated in this way becomes equal to crucible steel of the same chemical composition. High carbon steel ingots cast by the ordinary process often show a harder core, but when treated in this centrifugal machine they show a skin of harder metal on the top. This is a fraction of an inch in thickness, and it is explained by supposing that the more highly carburised metals have a smaller specific gravity than the rest of the metal, and accordingly come towards the centre of the machine or the top of the ingot. The advantages of this method are that the ingots are freed from blow-holes without any additions, that the carbon is uniformly distributed, that the piping is reduced about 60 per cent., that the fuel used for reheating is reduced in amount, as a welding heat is not required, and that the metal is equal to crucible steel of the same chemical composition.

Lining Bessemer Converters.—B. Versen * observes that when converters are lined with basic bricks, even when they have been most carefully made and built in, they rapidly corrode away in places; and in relining the converter a large portion of the valuable basic material has often to be thrown on the waste-heap. Stamping by hand is an improvement on this method, as far as the duration of the lining and its cost is concerned. Too long a time is, however, necessary in effecting this relining, and the author describes a mechanical arrangement, by the aid of which the lining can be stamped in as rapidly as the brick lining can be laid by ordinary labour. It consists of a central spindle, bearing arms, carrying pneumatic hammers.

Superheating Converter Metal.—R. M. Daelen † considers the question of the superheating of the metal in the Walrand and Legénisel method of Bessemerising with small converters. The use of the small converter was always accompanied by the difficulty of too low a temperature in the bath of metal. This was avoided by the addition of ferro-silicon in the case of the acid process, and of ferro-phosphorus in the basic method. Success, however, did not always result when these compounds were simply added to the bath during the boil, as the combustion was deadened by the large quantity of carbonic oxide present, and a considerable portion of the heat evolved carried away by the gas current. This led Walrand to make the addition only after the combustion of the carbon had entirely ceased, or at least was nearly completed. In this way a new combustion period results, and complete success was obtained—an addition of 5 per cent. of molten ferro-silicon producing an increased temperature of at least 200° within a few minutes' blow. It was then possible to carry the combustion of the still remaining carbon further than was possible in the older method, without adding such large excess quantities of oxygen. Consequently only a comparatively small addition of ferro-manganese is required to deoxidise the blown metal.

The Bessemer Plant at the Homestead Works.—The plant of this steelworks has been frequently described. Other drawings and a description of the converter plant are now given by A. von Ihering.‡ The converters are of 20 tons nominal capacity, the actual charges blown varying from 16 to 17 tons. The four converters make

* *Stahl und Eisen*, vol. xiii. pp. 919-920.

† *Ibid.*, pp. 830-832.

‡ *Ibid.*, vol. xiv. pp. 250-253, with two sheets of illustrations.

about 150 charges a day, or from 37 to 38 for each converter. Other drawings are given of the rolling mill plant, in which an ingot is completely rolled in little more than a minute, and of the ladle, crane, &c.

New American Bessemer Steelworks.—Each of the last four years has seen the completion of a new Bessemer steelworks in the United States. The close of 1893 witnessed the completion of another works in the plant of the National Tube Works Company at M'Keesport, situated on the Monongahela River, twelve miles above Pittsburgh. The works represent the most advanced views on the subject of Bessemer construction. The plant consists essentially of two 8-ton converters, mounted side by side, and the system of truck casting, vertical stripping, soaking pit furnaces, and electric travelling charging cranes has been followed. The published description* of the plant is illustrated by a two-page general plan of the works, and elevations of the converting and cupola house, and furnace building.

Basic Bessemer Costs.—The costs of manufacture of steel by the basic Bessemer process given by F. Tordeur† are discussed by an American writer,‡ with a view to compare them with possible results on similar work in the United States. The results appear to show that the American practice could fully equal the work cited.

Hydraulic Shifting Device for Ingot Trucks.—Illustrations have been published§ of a hydraulic shifting device for the trucks on which ingot moulds are carried. It is intended to be used instead of a locomotive for this purpose, so that the ingot moulds can be more readily adjusted exactly under the ladle. As shown, it consists of hydraulic rams placed between the two lines of rails on which the trucks run. Projecting arms pivoted on the ram heads can be moved in or out of engagement with notches on the underside of the truck framing, so that, by admitting water to the cylinders, the trucks can be moved in either direction. The device has been in successful use at the Duquesne Steelworks, and is also being erected at other works.

* *Iron Age*, vol. lii. pp. 891-892.

† *Journal of the Iron and Steel Institute*, 1893, No. I. p. 335.

‡ *Iron Age*, vol. lii. pp. 1119-1121, 1164-1166.

§ *Engineering News*, New York, vol. xxxi. pp. 152-153.

IV.—OTHER PROCESSES.

A New Direct Process.—A new process for the production of pig iron, refined iron, ingot metal, and weld metal is proposed by A. Sattmann and A. Homatsch.* It consists of the four following operations:—Heating of the ore and flux, and, if necessary, calcining the ore with gas fuel; reduction of the ore and carburisation of the resulting iron sponge with reducing gas; melting the carburised iron sponge by the direct combustion of solid fuel; separation of the slag from the resulting pig iron, and refining with oxidising gases immediately after the melting, thereby producing a more or less carburised metal. The ore may be calcined in a separate furnace, or in the reduction furnace. Any form of gaseous fuel may be employed, but it will be preferable to use waste gases over and over again by passing them over incandescent fuel, so as to regenerate them. By this means the amount of nitrogen in the gas is largely reduced, as the carbonic anhydride is reduced to carbonic oxide. The reduction of the nitrogen is considerable when spathic ores are treated, as the carbonic anhydride given off is utilised.

Immediately after the sponge is formed it is melted in the furnace in a non-oxidising atmosphere by the use of solid fuel, a sufficient thickness of fuel being used between the sponge and the tuyeres to generate carbonic oxide. The iron is made with a low content of carbon, silicon and phosphorus, and is desiliconised and decarburised on its way to the collecting chamber by means of hot oxidising gases.

Two ways of carrying on the process are described, one intermittent and the other continuous. Sketches of two kinds of furnaces to be used for each of these processes are also given. In one form a closed chamber for solid fuel is placed alongside a shaft-like furnace, into which the ore is fed. These two communicate below, and the junction forms the melting chamber, at the bottom of which may be a well for the reception of the molten metal, or the metal is allowed to flow directly to the refining chamber, which is made with a stepped bottom, down which the metal trickles and encounters hot oxidising gas. Ore and flux are charged into the shaft, and regenerated gas is admitted through a port near the top of the fuel chamber. Blast is applied through a tuyere in the bottom of this chamber, and combustion is carried on until

* *Transactions of the American Institute of Mining Engineers, Chicago Meeting, 1893 (advance proof).*

the ore is sufficiently heated. The blast is then turned off, and reducing gases alone are admitted until the ore is reduced. Some additional heat may be generated during this period by admitting some blast. After the reduction is complete, the fuel chamber is charged and the blast again turned on, and the sponge is melted down. Slag and metal are tapped, and the furnace is ready for another charge. In the continuous method, arrangements are made for introducing blast and gas directly into the shaft part of the furnace for the reduction process, while solid fuel is burnt in the lower part to melt the sponge. This fuel is either drawn from a fuel chamber, as described above, or is introduced continuously. The refining chamber may terminate in or lead the metal to an ordinary open-hearth furnace with the usual regenerators.

The authors then proceed to calculate for a given ore, flux and fuel, the thermal results of the process, and their conclusions are set forth at length in fourteen tables. These show in detail the amount of heat generated in the several operations and its utilisation, and are shortly summarised as follows :—

	Per Cent.
Reduction	22·60
Heating final product	7·14
Heat in by-products	4·46
Heat in gases	34·19
Loss by radiation	32·35

FURTHER TREATMENT OF IRON AND STEEL.

The Manufacture of Steel Castings.—H. L. Gantt * reviews the progress made in steel founding during the past two or three years, and gives a brief record of the development of the industry in the United States, which dates from about 1886. Hotter metal and larger heads are now used. The use of hotter metal tends to prevent the development of leaks in the nozzle of the casting ladle. It also causes the silicon spiegeleisen, which is added to prevent blow-holes, to melt and mix more thoroughly. In the best foundries it is the practice to previously melt the added metal. Castings are now more frequently designed with the heaviest part uppermost at the sink head, so that they cool from the bottom upwards. The sink head is usually made about 20 per cent. of the weight of the casting. By making castings as far as possible of uniform thickness, they have been made as large as 20 feet long by 10 feet wide. Most foundries use open-hearth furnaces melting from 5 to 20 tons. The difficulty from the cooling of the metal in the ladle may be obviated by using small Bessemer converters, which will give 2 or 3 tons as hot as desired. This also permits the manufacture of several grades of steel in the day. A recent important improvement consists in making certain faces of the castings much harder than the body. This is effected by lining the faces of the mould, which will lie against the surfaces to be hardened, with an alloy in a powdered state. For stamp shoes, crusher jaws, and hammer dies, ferro-manganese is the best. If, however, it is desired to machine the face, and to subsequently harden it, ferro-chrome is the most suitable.

J. S. Owen † discusses the action of silicon, aluminium, and manganese in preventing the formation of blow-holes in steel castings. For

* *Transactions of the American Society of Mechanical Engineers*, vol. xv. (advance proof).

† *Iron Age*, vol. lii. p. 969.

castings that are liable to draw and crack in cooling, manganese is, he considers, essential, its presence giving the casting strength when in the semi-solidified condition. Manganese, when added to oxygenated iron, removes the oxygen, and is thus a cure for red shortness by setting free intermixed particles of slag as a double silicate of manganese; at the same time it is a carrier of sulphur in the slag. Steel foundrymen appear to fear a high percentage of manganese in their castings. The author, however, has seen steel castings, carrying as much as 0·85 to 0·95 per cent. of manganese, which proved very tough and strong. This does not support the theory that five parts of manganese are equal to one part of phosphorus in producing brittleness.

Heavy Steel Casting for Marine Work.—The *Iron Age** reproduces a photograph of the steel strut for the screw shafts of the new Inman liner built at Philadelphia. It is the largest casting yet used for marine work in the United States. Its weight is 67,135 lbs. While the largest castings called for can now be successfully produced, it is still extremely difficult to make the smaller ones, where, by reason of coring and of the limited quantity of metal, it is almost impossible to avoid the blow-holes which render them so untrustworthy.

Electric Welding.—H. Zerener,† referring to the Lagrange and Hoho‡ method of electric welding, observes that the use of the electric arc for this purpose has long been suggested, even Davy in 1807 having drawn attention to this. The author mentions the more recent methods of Bernardos, Coffin, and others, as well as the now well-known Thomson process.

Edward J. Duff§ describes the various electrical processes for welding metals. In the Thomson process, the heating effects set up by the resistance to a large volume of current at a very low pressure passing through the pieces of metal to be welded, generate a sufficient temperature to effect the welding very speedily, the volume of current ranging for wire welding up to 50,000 ampères, and in some instances to as much as double that quantity. Not only similar but dissimilar metals can thus be united, in a manner which a series of exhaustive tests proves to be fully as strong as if no joint had ever been made.

The Thomson machine is then described in considerable detail, and

* Vol. lii. p. 693.

† *Stahl und Eisen*, vol. xiii. p. 1060.

‡ Compare *Journal of the Iron and Steel Institute*, 1893, No. II. p. 478.

§ Paper read before the West of Scotland Iron and Steel Institute.

attention is drawn to numerous specimens of its products, amongst others a gun-barrel spirally welded, and an artillery shell formed of a piece of tube with both ends welded on. The Bernardos, or arc-welding process, employs a current of about 300 ampères, with a voltage of 100. Instances are quoted of the great services rendered by this process; in one case a cast-iron flywheel, weighing 5 tons, which had been broken in transit, being in one day effectively welded and rendered serviceable. The power of the current to produce holes in metals is fully detailed, and experiments are quoted to determine the result of such treatment on the physical properties of the materials under manipulation. In conclusion, the latest and most approved practice of Messrs. Lloyd & Lloyd of Birmingham, in regard to the electrical welding of tubes, is fully described.

Electric Welding of Rail Joints.—It is highly necessary to dwell upon the desirability of abolishing rail joints. Could this be accomplished, the resulting economy would justify a considerable outlay. In the United States, the experiment is being made of electrically welding considerable lengths of rails into one continuous rail. The results of experiments made by A. J. Moxham* at Johnstown, Pennsylvania, show that the paving packed about the rails in street lines, prevented any change of the line either in length or alignment, that whatever linear expansion took place was expended in compression and consequent enlargement of the rail section, and that the paving prevented any lateral motion or buckling of the line. At Johnstown, a line has been laid down 3000 feet in length, with the joints welded up solid, and although subjected to a range of temperature of 30°, it has not exhibited any linear or lateral motion. Descriptions are given of the apparatus used for welding together 16 miles of line at Cambridge, Massachusetts.

Heavy Steel Forgings.—In a paper read at the first annual meeting of the Society of Naval Architects and Engineers, R. W. Davenport† traced the history and development of the forging plant of the Bethlehem Iron Company, Pennsylvania, and exhaustively discussed the conditions necessary, and the most improved methods employed for producing uniformly trustworthy forgings of such quality as to offer maximum resistance to working strains. He dealt with the subject under the following heads :—(1) the casting of ingots; (2) the conditions of shaping and forging; (3) the treatment after forging; and (4) the introduction of unusual

* *Railroad Gazette*, vol. xxv. pp. 518-519.

† *Iron Age*, vol. lii. pp. 926-927, 971-973.

ingredients into the composition of the steel, intended to give to it desirable qualities. In conclusion, he dealt with gun forgings, armour plate, and marine shafting and engine forgings.

In marine engine forgings, by the use of hollow shafts made of stronger steel, there is a gain in strength of three to one, and a reduction in weight of more than one-half as compared with solid steel shafts of equal weight and equal strength respectively.

Wheel Forging Machine.—Illustrations have been published of a new wheel forging machine, invented by W. A. Pearson.* The machine is in successful operation at the works of the Boies Steel Wheel Company at Scranton, Pennsylvania. The hammer has a comparatively light piston and tup or die holder, with a strong and heavy piston rod, and guides are provided for the die, which guide it during its entire stroke, so that the blow is delivered with the utmost accuracy. At the same time, the piston rod is practically indestructible, and the blow is more effective because the weight is concentrated directly above the blank in the piston, instead of overhanging it as in the case where the weight is in the tup. A novel feature of the upper die is a central projection upon the face of the die, which forms a corresponding depression in the hub of the blank adapted to centre and hold the punch, which is afterwards used to form the hole through the hub.

Work in Hot-Pressed Steel.—Illustrations have been published † of hot-pressed steel work of an unusual character performed at the works of the United States Projectile Company, Brooklyn. A steel bottle and work of a similar character, such as heavy U-shaped cups, heads, and discs, are made from plate steel up to 1 inch or more in thickness. Steel pressure vessels for holding gases are made by a process very similar to that used in the manufacture of projectiles, the solid billet being first heated, and then, by successive passes through powerful machines, brought to the desired form in one piece without seam or weld. The process has been further extended to the formation of hot-pressed steel pinions.

Hydraulic Shell Plant.—Illustrations have been published ‡ of a number of hydraulic machines recently constructed by Fielding & Platt,

* *Iron Age*, vol. lii. pp. 1015-1017, with eight drawings.

† *Ibid.*, pp. 1021-1022, with four drawings.

‡ *Engineering*, vol. lvii. p. 12.

of Gloucester. The machines shown are a double-ended hydraulic press for drawing forged steel projectiles of from 3 to 5-inch calibre, and a vertical press for partially closing the ends of 3-inch projectiles, or for drawing the bodies of 3-inch shrapnell shell.

Hardening Steel.—H. Wedding* considers various American processes for hardening steel. In the Harvey process† the carburised plate, if it has been produced by cementation with charcoal, is hardened by cooling with water, but it is stated that if the carburisation has been effected by the use of petroleum this in itself evaporates sufficiently rapidly to adequately lower the temperature to produce a sufficient degree of hardness without the use of any special hardening agents. The author points out that it is evident that in this, as in all other carburising processes, it is the temperature which plays the most important part.

Another process, employed at the Cambria Steelworks, consists of cold rolling, which is employed in the manufacture of pulleys for the transmission of power. It is stated that the result of this treatment is to increase the tensile strength from 15 to 35 per cent., while the limit of elasticity is raised by as much as 40 or 50 per cent.

A third method, known as the Coffin process, is based upon the heating of the metal to from 1250° to 1300° C., then rapidly cooling to a dull red by plunging in water, followed by slow cooling in air. Photographs of sections are given, showing the change in structure produced by this toughening process. The limit of elasticity is raised without any diminution of the toughness. The following are the results of mechanical tests of the metal before and after this treatment—

	Limit of Elasticity. Lbs. per Square Inch.	Tensile Strength. Lbs. per Square Inch.	Elongation per Cent.	Diminution of Area per Cent
Before treatment . . .	30,000	71,520	24.50	51.50
After treatment . . .	44,000	72,020	24.07	57.20

This process is largely employed in the manufacture of the axles of railway waggons.

O. Harner ‡ gives some of the results of his experience in connection

* *Stahl und Eisen*, vol. xiii. pp. 1084-1035.

† Compare *Journal of the Iron and Steel Institute*, 1893, No. II. p. 483.

‡ Paper read before the Mason College Engineering Society, 1893. *Industries and Iron*, vol. xv. p. 919. Also paper read before the London Association of Foremen Engineers and Draughtsmen, *Industries and Iron*, vol. xvi. p. 375.

with gas furnaces and hardening special tools and other articles. The advantages of gas furnaces over other forms of furnaces for these purposes are that the temperature can be readily controlled and the uniformity of the heating assured, free carbon is kept from contact with the work, and the furnace is simple. A gas oven furnace for annealing and hardening is described.

Chilled Railway Wheels.—W. Hartmann * observes that the majority of the wheels of railway waggons in the United States are made of chilled castings. Such a wheel should have—(1) a perfectly cylindrical running surface; (2) this surface and the portion of the flange which comes in contact with the rail should be perfectly smooth and remain so in wear; (3) the hard casing of chilled metal should not be thicker than 0·8 inch, nor thinner than 0·4; (4) there must be no sharp line of demarcation between the chilled casing and the soft interior, but there should be a gradual transition from one into the other. As a matter of fact, such perfect wheels do not occur. The wheels are made as cheaply and as rapidly as possible, and the necessary care in their manipulation is not taken. The author considers the faults of these wheels as being due in part to cracks in the chilled casing; to roughness in the running surface, due to a rising of the metal in the mould; to slag in this running surface, to liquation, to irregular thickness of the chilled portion of the casting, to too thick or too thin a casing; to faults in the circular shape of the wheel, due to unequal expansion of the moulds, or to irregular contraction of the wheel body. Each of these points is considered, and the author shows that the casting of a perfect wheel is rendered difficult; (1) by the fact that the tendency of the metal to show cracks causes the workman to pour slowly and to use colder metal; (2) by the fact that the slow pouring and the cold metal cause rough surfaces, lead to the non-separation of slag from the running surface, to liquation, and to irregularity in the thickness of the chilled casing; (3) by the expansion of the mould and the contraction of the wheel, causing frequent errors in the circular shape of the wheel, as well as change and diminution in the thickness of the crust. To avoid these difficulties, J. M. Barr has designed a mould which the author describes and illustrates. It has been given the name of “contracting chill.” This mould consists of an inner one divided into 96 sections, which are contained in an outer ring, which, in turn, by heating or cooling, can be expanded or contracted.

* *Zeitschrift des Vereines Deutscher Ingenieure*, vol. xxxviii., pp. 292-294, six illustrations.

The method of using this mould is described, and the results accompanying its use are shown to be most satisfactory. Over 1400 of these moulds are in use in the United States.

Metal Underframes for Rolling Stock.—G. R. Joughins* recounts his experience with tubular underframes for railway vehicles, and of a special form of underframe built to obviate some of the defects of the tubular type. These had four sills, each of two tubes one over the other, and were too light for recent traffic requirements. In the second form, six longitudinal sills of 8-inch steel channels are used, with 12-inch end sills. Cross and diagonal ties are made of gas piping, and rods are used for trussing the frame longitudinally, the depth of the truss being $21\frac{1}{2}$ inches below the sills. The trunk is 34 feet long and designed to carry a maximum load of 80,000 lbs. Its weight is 20,300 lbs. without brakes. Under the maximum load for ten days, a set of $\frac{1}{4}$ inch was produced. Common rolled sections and plain forgings are used without holes in the flanges of the beams. No rivets are used, but turned bolts with a driving fit are employed.

J. D. McIlwain† gives the life of wood trucks as twelve years, and estimates that a steel frame would last four times as long and would require less for maintenance. Several forms are described, and the use of standard sections is urged. For passenger vehicles, two centre sills of 12-inch I-beams, with six other sills of 8-inch I-beams, are suggested.

The Leeds Forge Company‡ have recently added a large department for the manufacture of steel underframes for rolling stock. It consists principally of a large building, covering 12,000 square yards, and it contains plant for hot stamping the various parts used for underframes on the Fox system. Illustrations are given of several forms which have been in use.

Sketch drawings are published by G. Lentz§ of locomotive frames made of steel castings. Hitherto it has been customary to make these of plates riveted together, and Lentz draws attention to the much greater strength and to other advantages of the cast steel frame he has designed. Basic open-hearth steel is the material employed in these castings.

* Paper read before the New York Railway Club, January 18, 1894, through the *Engineering News*, New York, vol. xxxi. pp. 87-88.

† Paper read before the Western Railway Club, December 1893, through the *Engineering News*, New York, vol. xxxi. pp. 87-88.

‡ *Engineering*, vol. lvii. pp. 446-447, thirteen illustrations.

§ *Stahl und Eisen*, vol. xiv. pp. 209-212, four illustrations.

Fire-bars of a Manganese Steel Alloy.—At the Storek Iron Foundry, Brünn, fire-bars are made by mixing with a special kind of iron, 40 per cent. of manganese steel. These bars are stated to have a melting-point about 400°C. higher than ordinary cast iron bars, and to be proportionately more fire-resisting.*

Early Steel Bridges.—A list of early steel bridges in America has recently been published,† with their dates and the names of the steel manufacturer. This has called forth some correspondence on the subject, additional particulars being given by several writers. Amongst others, G. Lindenthal describes the eyebars and plates used in a Pittsburgh bridge in 1881. The eyebars were 7 inches by $1\frac{1}{2}$ inch. Their shanks were rolled in reversible rolls, leaving the ends thick for subsequent forging under a hammer, no dies being used. At that time, plates 28 feet long by 20 inches wide and one inch thick, could not be obtained in the United States.

In the course of a description of some of the large aqueducts in France, Mazoyer ‡ gives a short historical account of the employment of steel in bridge construction. This has led to some correspondence by C. Rabut, A. de Serres, and E. Cheysson. § The latter describes a steel bridge erected in 1867 for the exhibition of that year.

The Manufacture of Pipes.—This manufacture as carried on at M'Keesport in Pennsylvania is described by Uhr. || The works possesses a couple of furnaces, one for heating up the sheet strips that are to be used in the manufacture of the pipes, and the other used in the welding of this material. The edges of the strips are bevelled in the cold by a machine. The strips are then forced into the heating furnace at one end, and the heated strips withdrawn from the other. The heated strip is only partially withdrawn at first, a workman bending up the ends, the end of the strip so bent being then inserted into a shaping machine, through which it is drawn by machinery, and in which it assumes the shape of a pipe, the lapped edges being further closed up by direct hammering wherever necessary. The pipe then passes into one end of the welding furnace, and out at the other to a series of rolls, which, by the aid of a die placed inside

* *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xli. p. 587.

† *Engineering News*, New York, vol. xxx. p. 516, xxxi. p. 120.

‡ *Le Génie Civil*, vol. xxiv. pp. 49-53. § *Ibid.*, pp. 143, 174, 270.

|| *Eisenkontorets Annalen*, vol. xlviii. pp. 71-76.

the pipe, rapidly and completely close the joint in the lapped piping. The pipe thence passes to shaping rolls, and is finally tested by being subjected to hydraulic pressure.

The Manufacture of Tin-Plate.—H. Wedding* inquires, why is it that the United Kingdom is by far the largest producer of tin-plate? After referring to the sources of supply of tin, he quotes a comparison as to the relative cost of manufacture of tin-plate in the United Kingdom and in the United States.†

The enormous importance of a cheap source of supply of tin-plate for the United States is shown, and the author gives a list of the more important tin-plate works in the United States. He then shows that although in the interval the heavy protective duties of the M'Kinley tariff had been introduced, yet the quantity of tin-plate exported from the United Kingdom to the United States, actually increased between the years 1889 and 1891, to the extent of over 16,000 cwt., the quantities being :—

Years.	Cwt.
1889	6,730,262
1890	6,283,280
1891	6,746,360

The author describes and illustrates various appliances used in tin-plate works, including the trains of rolls, the dipping tanks, and machinery for cleaning the finished plate. He considers that the position held by the United Kingdom in the tin-plate trade is solely dependent on the skill which long years of practice has led to in the British workman engaged in this trade.

The Manufacture of Nickel.—The rapidly increasing use of this metal in the metallurgy of iron renders it desirable to give some details as to its method of manufacture. D. Leval‡ states that the reduction of nickel from its ores resembles in part the reduction of iron from its ores by means of coke, and in part the metallurgy of copper, owing to the great affinity possessed by nickel for sulphur. The nickel ore is usually run down in cupolas with 20 per cent. of coke, such a cupola smelting 20 or 25 tons of ore a day. The product is a regulus, with 50 or 55 per cent. of nickel, 25 to 30 of iron, and 16 to 18 of sulphur.

* *Stahl und Eisen*, vol. xiii. pp. 976-979.

† *Journal of the Iron and Steel Institute*, 1892, No. II. p. 527.

‡ *Teknisk Tidsskrift*, 1893, p. 39.

This is then concentrated either in a reverberatory furnace or in a Bessemer converter. In the reverberatory treatment the ore is first calcined and then fused down, the products being a slag containing 2·5 per cent. of nickel that can be re-treated with the next ore charge, and a concentrated regulus containing only 2·5 or 3 per cent. of iron. By a second concentration this percentage can be still further reduced to from 0·5 to 0·75, the sulphur remaining approximately constant.

In the converter a ton of regulus is blown with a blast pressure of 15 or 16 inches of mercury. The combustion of the sulphur causes the temperature of the bath to rise, and sand is added to slag off the iron oxide produced. If the percentage of iron did not exceed 36, the elimination is complete in an hour and twenty minutes. If the percentage is greater than this, the slag must be run off and the blow continued. When the slag shows the presence of nickel it is run off, and the now concentrated regulus poured. It will be found to contain less than 0·5 per cent. of iron. Any cobalt originally present remains in the regulus. The slag is much richer in nickel than that made in the reverberatory, and contains 14 or 15 per cent., partly as shots of regulus. Nickel free from copper has almost the same melting-point as iron, and a continuation of the blow beyond the stage of the concentrated regulus does not affect the elimination of the sulphur as the bath chills. If copper was originally present in the ore treated, it will still remain in the concentrated regulus. This is crushed and passed through a trommel. It is then again roasted in reverberatory furnaces, a sufficient quantity being charged to form a layer, about 2 inches thick, on the bed of the furnace. If the regulus is free from copper, the calcination lasts about eight hours, while the time required is only six hours if copper sulphide is present. The furnace temperature is a dull red, but towards the end of the operation this is increased to bright redness. The product must not retain more than 1 per cent. of sulphur. This oxide product is now moulded into small pieces with flour, dried, and melted down in crucibles with charcoal, or, better still, in a kind of Belgian zinc retort, open at both ends, and heated in a reverberatory furnace. Such a furnace, with twenty-two retorts, will treat a ton and a half of nickel oxide, or twice that quantity of the mixed nickel-copper oxide per shift, 2 tons of coal being required. The reduced metal is broken up, sifted, polished in rotating drums, and packed in barrels holding 2 cwt.

PHYSICAL PROPERTIES.

The Microscopic Investigation of Steel.—In the discussion on the several papers on the microscopic structure of steel,* W. R. Webster † mentions that the relationship of the chemical and physical characteristics may be dependent on the size of the grain, which is partly controlled by the temperature at which the metal is worked.

R. A. Hadfield thinks that the size of the grain, as a rule, should be kept small, but notes that some German steel castings, with coarse fractures, gave good results in tensile tests, although they were not so good under drop tests.

P. H. Dudley remarks that the surface appearance of a test piece during a tensile test is a good indication of the size of the grain, as it shows a reticulated structure if the grain is large. Chemical homogeneity does not necessitate a similar physical character. In the earlier steel rails rolling at low temperatures produced a finer grain, in which the different constituents were thoroughly interlocked. With more rapid manufacture and higher temperatures the grain is coarser, so that the wheel-pressure broke down the particles, and caused the rail to wear pitted and to flow more readily. Four illustrations are given of sections of these rails. The form of the section has great effect on the size of the grain in rails, and those proposed by himself, with broad thin heads and high carbon contents, have given good results. The use of wide-angled, low-power objectives in connection with natural illumination, is then discussed.

A. Sauveur describes the materials he uses for polishing sections, steel being prepared in about an hour, and cast iron in half an hour. The oxyhydrogen light is used for photographing the sections, and some photographs of sections magnified 1000 diameters have been produced. Attention is called to the concordance between most of Osmond's results and his own investigations.

* *Journal of the Iron and Steel Institute*, 1893, No. II. p. 488.

† *Transactions of the American Institute of Mining Engineers* (advance proof).

H. M. Howe agrees that the microstructure is of the greatest importance, but is of the opinion that the study of the fracture also affords valuable indications. The terms cementite, ferrite, &c., are defended for provisional use only. It is assumed that there is a constant relation between the microstructure of steel and its physical properties, and it is now time to experimentally determine this relation rather than to pursue the study of microstructure for its own sake. The size of the grain in some instances only indicates the treatment that the metal has undergone, as is shown by two pieces from the same runner of manganese steel. One, before water toughening, is relatively brittle, and has a fine grain, whilst, after treatment, it is strong and ductile, with a coarse columnar fracture.

H. Wedding* observes that the use of the microscope in the manufacture of steel has made greater progress in the United States than in Germany, thanks largely to the efforts of G. W. Goetz. A large microscopic laboratory has been erected for experimental purposes at the works of the Illinois Steel Company at South Chicago. Photography is used instead of drawings, and this the author refers to. He also refers to the work of Osmond, Howe, Sauveur, and others in this direction. The last mentioned experimenter has found that in a steel rail head the structure of the core is larger grained and less compact than is the surface portion—a fact which the author himself observed in 1891 in the case of the Goliath rail, but which has since been much disputed. The older work of Sorby is also mentioned.

Spectrum of Electrolytic Iron.—A series of photographs was taken by J. Norman Lockyer† of the part of the spectrum between the K and C Fraunhofer lines. Electrolytic iron of a very high degree of purity was employed, and the spectrum obtained by using this as the poles of an electric arc lamp. The results are compared with those previously obtained by Thalén, Kayser and Runge, and M'Clean, the agreement being in all cases satisfactory. Many lines occur in the spectra of the other observers, however, which are not indicated in these photographs. In many cases they are due to impurities in the iron used by them; in other cases, however, they appear to be owing to differences in temperature, or to insufficiency of exposure of the photographic plates. Evidences were obtained of calcium and manganese in the specimen of electrolytic iron employed, as well as of very minute traces of other metals.

* *Stahl und Eisen*, vol. xiii. p. 974.

† *Proceedings of the Royal Society*, vol. liv. pp. 359-361.

The Chemical Composition and Physical Properties of Steel.

—Prior to the paper in the present volume on the relationship of the chemical composition and the physical properties of steel, W. R. Webster * had published another paper, which is a continuation of his earlier researches on the same subject, and contains some slight corrections. Some discussion is appended, and in it the author offers to co-operate with Mr. Sauveur in his microscopic investigation to determine the relation between the size of the grain and the physical characteristics of the metal after work at different temperatures.

A. Ledebur † discusses W. R. Webster's ‡ research on the relations which exist between the chemical and the physical properties of steel. He observes that the chemical composition is an all-important factor where the physical properties of the metal are concerned. In addition, of course, there is the shape and size of the ingot from which the metal was rolled, the method of treatment to which it was subjected, the extent to which this treatment was carried, and, amongst other points, the existence of blow-holes or other local points of weakness, which may have existed in the ingot before it was subjected to the rolling process. The influence of the shape of the metal has often been studied, but that of the chemical composition is still less understood. After referring to Webster's various experiments, the author compares the actual results of the tensile tests with the theoretical results to be deduced by making allowances for the various elements which existed in the metal, the composition of which varied within the limits:—

Carbon.	Manganese.	Sulphur.	Phosphorus.
0·06—0·19	0·255—0·667	0·025—0·079	0·005—0·095

The comparative results show that the differences between the theoretical and the actual tensile strengths were as follows:—

Per Cent. of the Tests.	Difference. Tons per Square Inch.
94·9	2·22
89·9	1·78
74·7	1·40
55·1	0·95
28·4	0·44

The results show, therefore, that those deduced theoretically from a consideration of the qualities of the various elements present in the

* *Transactions of the American Institute of Mining Engineers* (advance proof); *Journal of the Iron and Steel Institute*, 1893, No. I. p. 374; No. II. p. 490.

† *Stahl und Eisen*, vol. xiv. pp. 61-64.

‡ *Journal of the Iron and Steel Institute*, 1893, No. II. p. 490.

metal tested were in satisfactory agreement with those actually obtained in practice, although it may be pointed out, perhaps, that the limits within which the percentages of these several foreign elements vary are relatively very slight, and that consequently large differences between the theoretical and the actual results are impossible. Still, the lowest and the highest of the calculated tensile strengths varied by as much as 10 tons per square inch. For metal containing higher percentages of carbon, phosphorus, and manganese, these experiments would have to be extended.

The Flow of Solids.—W. Hallock * summarises the experimental work upon the question of the flow of solids by W. Spring, Friedel, Jannetaz, and Tresca, and describes the tests made by himself with the Watertown testing machine. The results show that pressure alone cannot truly liquefy a solid, that is, diminish its rigidity. Chemical and crystalline changes can therefore scarcely be expected to be brought about by pressure alone. Solids can be made to flow and act, in that respect, as liquids, by pressure, which overcomes the rigidity without diminishing it. In this case the time allowed for the motion is of vital importance. A bibliography of the subject is appended to the paper.

Magnetic Qualities of Iron and Steel.—G. Kapp † describes the methods that he uses for testing the magnetic qualities of iron for dynamos and transformers. The quality of the iron for the former is not so important as for the latter, as more iron and more copper can be used, but a good transformer cannot be made with inferior material. The apparatus for testing bars is a form of electro-magnet with the sample forming the centre, and the other limb being made of a frame. The solenoid is made of several windings, any number of which can be put into circuit. The armature, in the form of a plunger, is loaded until it is torn off. For testing plates the apparatus consists of a closed magnetic circuit of rectangular shape, one of the longer sides of the rectangle being formed of a bundle of the plates to be tested. Any number of samples are made up into bundles, and can easily be substituted one for the other. The apparatus is calibrated by making this

* *Annual Report of the Board of Regents of the Smithsonian Institution to July 1891*, Washington, 1894, pp. 237-246.

† *Journal of the Institution of Electrical Engineers*, vol. xxiii. pp. 199-233, through *The Electrician*, vol. xxxii. pp. 498-502.

bundle of the same quality as the rest of the iron circuit. The coils are connected to a source of alternating current through a watt meter, by which the losses are tested. A lengthy discussion ensued, on the reading of this paper, and different methods were described.

S. Evershed,* in commenting on magnetism and iron manufacture, states that the physical state seems to have more to do with permeability than does the chemical composition. Many facts bearing on this subject are already known, but have not been marshalled, so that the only resource of the buyer at present is to test frequently, and to buy from the tested sample.

S. J. Lochner† gives the results of an extended research on the elongation produced in soft iron by magnetism. The elongation was measured by a mirror instrument, which was sensitive to below one-millionth of an inch. It was found that the rate of magnetising the iron affected the stretch, which, when plotted as a curve, is somewhat similar to a hysteresis cycle. The expansion appears to be a function of the ratio of the diameter and length, probably the square root of this ratio. It varies directly as the permeability. The amount of magnetising force for producing maximum or zero expansion depends on the ratio of diameter and length. There are two maximas, one produced by increasing the current, and another by decreasing the current from the point which produced the first maximum. The first contact gives more expansion than succeeding contacts, which also appear to disagree amongst themselves. A large number of diagrams and tables are given in the paper.

H. Nagaoka‡ describes an elaborate research on the hysteresis attending the change of length by magnetisation in nickel and iron. The apparatus used is described in detail, and the results are plotted as curves, numerical results being also given. With iron the elongation increases to a maximum in a field of 70 C. G. S. units, and then decreases as the field is increased to 305 units. On reducing the field, the curve of elongation crosses the other at 120 units. A similar occurrence takes place in a negative field.

Professor C. G. Knott§ gives some of his results, which confirm the above results, and states that they agree with what was to be expected from the character of the hysteresis in the magnetic cycle.

W. Kunz|| has experimented on the dependence of magnetic hysteresis,

* *The Electrician*, vol. xxxii. p. 481.

† *Philosophical Magazine*, vol. xxxvi. p. 498.

‡ *Ibid.*, vol. xxxvii., No. 224, p. 131.

§ *Ibid.*, p. 141.

|| *Annalen der Physik und Chemie, Beiblätter*, vol. xviii. p. 229.

permeability, and the electrical conductivity of iron and nickel on their conductivity. The temperature was measured by a thermo-couple, and was produced by a platinum spiral heated by a current. It is concluded that the work done in overcoming hysteresis in a magnetic cycle of given amplitude for soft iron varies with the temperature, becoming smaller with increasing temperature. For steel the work increases slightly at first up to 300°, and then falls, at first very quickly, and subsequently with decreasing rapidity. In soft iron, the hysteresis loss H is related to the temperature, as shown by the formula $H = a - bt$, where a , b are constants depending on the quality of the iron, and independent of the maximum induction of the cycle. After cooling the wire to the original temperature, the hysteresis is no longer so great as before the heating. If the cycle is repeatedly performed at a high temperature, the hysteresis loss is considerably reduced.

P. Curie * finds that soft iron retains its magnetic properties at high temperatures, and he gives the magnetic co-efficient for temperatures ranging from 755° to 1365° C. This is independent of the intensity of the field between 25 and 1350 units. The results are also plotted as curves, and these show that there is no particular temperature at which iron changes. In a general way, the magnetic property decreases slowly at first, and then falls most rapidly about 740° to 750° C. Above 750° C. it decreases more and more slowly, but the relative variation is always considerable between 750° and 950°. From 950° to 1280° the co-efficient is nearly constant, but towards 1280° it suddenly increases by half its value, and then from that point up to 1365° it again diminishes. Soft iron also shows another peculiarity at the temperature of 860°. This is scarcely seen on the curve of the magnetic co-efficient, but is very visible on a logarithmic curve, which shows the rate of change of the co-efficient. This curve shows two points of inflection at 840° and at 880°, besides the first point near 750°. When the temperature diminishes from the point of transformation, the intensity of magnetisation for a given field increases, and then tends towards a constant value independent of the temperature, and otherwise higher as the field is stronger. Between 20° and 720°, the intensity tends towards a constant value as the field becomes stronger. This would seem to show that there is a limiting curve for the intensity in function of the temperature in strong fields. This curve, between 20° and 730°, would be similar to that shown for a field of 1300 units, but would break away from it above 750.

* *Comptes Rendus de l'Académie des Sciences*, vol. cxviii. p. 859.

P. Joubin* discusses the law of the magnetisation of soft iron. The phenomena are represented at present by empirical and approximate expressions, but the author shows a formula which gives results that accord almost exactly with observed results. It is shown that the phenomena of magnetisation are analogous to those offered by a saturated fluid and can be calculated by the same formulæ. Feebly magnetised bodies come under laws analogous to those of fluids far from their points of saturation. The characteristic equation of the intensity of magnetisation is given in terms of the susceptibility. In a further communication, this is confirmed by the author, who gives a number of experimental results.

The Use of Steel in Electric Machines.—H. F. Parshall † discusses the recent changes in the use of steel for iron in electric machinery. For motors, the substitution of cast steel and steel forgings has been of great advantage on account of the reduction of weight, and the increase of strength and efficiency. In stationary motors and dynamos the advantages are not so marked, but in any case the reduction of the size of the magnetic parts also diminishes the amount of copper required in the windings. The effect of combined carbon and graphite is to lessen the magnetic continuity and permeability. Analysis often does not show the quality of the steel on account of blow-holes, but, roughly, good cast steel should not contain more impurities than—

Carbon.	Manganese.	Silicon.	Phosphorus.	Sulphur.
0.25	0.60	0.20	0.08	0.05

Carbon should be reduced as far as possible, but manganese below 0.6 per cent. has no appreciable effect. Silicon at the magnetic densities used in practice is less objectionable than carbon. Annealing seems to increase the permeability for low magnetisations, but at high magnetisations the effect is less marked. Tempering greatly diminishes the permeability, as also does compression. For the sheets used in armature cores, the metal has to be of good quality to permit of its reduction to the required thinness. The chemical composition has less influence on the hysteresis losses than slight differences in annealing; phosphorus is, however, especially objectionable. Illustrations are given of several of the forms of castings employed, and also a number of curves and tables to show the magnetic properties of the metal. The castings should be free from blow-holes and surface defects, and should be soft and easily

* *Comptes Rendus de l'Académie des Sciences*, vol. cxviii. pp. 67-69, 138-140.

† *Journal of the Franklin Institute*, vol. cxxxvii. pp. 93-107.

machined, requiring a minimum of finish. Such castings would certainly prove satisfactory from a magnetic standpoint.

The Absolute Measurement of Hardness.—F. Auerbach* believes that, taking Hertz's conclusions as a point of departure, he has solved the problem of the measurement of hardness, and he submits a method which seems to lead to satisfactory results, both from theoretical and practical points of view. His paper comprises a review of the earlier work, descriptions of the theory, the method in general, the apparatus, and general remarks on the observations, the constants and sources of error, the experimental verification of the method, and the measurements of the elasticity, and of the hardness of certain substances. Theory shows that to compute hardness by the aid of the phenomenon of contact between a sphere and a plane of a given body, the total pressure under which contact takes place is to be increased up to the elastic limit. The time of yielding being sharply marked by the occurrence either of permanent set or of rupture at the area of contact, it is merely necessary to measure the total pressure and the diameter of the impressed area for the time in question. From these observations the value of theoretical hardness is calculated.

The Alteration in Iron produced by Strain.—According to G. Charpy† no conclusive proof has been offered up to the present that the transformation of α and β iron can be produced by a permanent deformation produced by a strain on the metal. The most decisive proofs have been offered by the actions of chloride of copper on the worked and annealed steel, but the annealing necessitates heating. The author, however, has tested pieces of a test piece taken at points on the curve of elongation and load which are near the step indicating the elastic limit. These pieces have been tested by magnetising them, and by testing the residual magnetism after twenty-four hours. The results differ greatly according to the load applied in each instance, but they are restored to a normal amount by annealing. It is thus seen that there is a considerable change in the metal, and this is provisionally ascribed to allotropy.

In the previous note on the transformation of iron under the influence

* *Annalen der Physik und Chemie*, vol. xliii. pp. 61-100; translation by C. Barus. *Annual Report of the Board of Regents of the Smithsonian Institute*, Washington, 1894, pp. 207-236.

† *Comptes Rendus de l'Académie des Sciences*, vol. cxvii. pp. 850-853. 1891.—i.

of heat, G. Charpy * has shown that iron under the influence of strain at ordinary temperatures seems to show an allotropic transformation. Adopting Osmond's notation, α iron should give a step in the stress-strain curve, and β iron a continuous curve. The length of the step may therefore be an indication of the amounts of the two varieties present. This method of investigation has been applied by the author, who gives a number of results, and draws the following conclusions: The allotropic change is produced spontaneously at a high temperature, and can be maintained by sudden cooling. The change is quicker as the temperature is higher, so that duration of heat as well as the temperature is important. These experiments show that in quenching the iron undergoes a change which can equally be produced by working in the cold, but they do not show that the change is the cause of the hardening of steel.

The Effect of Suddenly Applied Loads.—E. D. Estrada † gives the results of a long research on the effect of suddenly applied loads upon the tensile strength and other physical properties of wrought iron and steel. In the apparatus used, the test piece is supported vertically at its upper end in a fixed cross piece, and its lower end carries a frame which extends upwards over the test piece, where it ends in a crosshead on to which a weight is let fall from any desired height. The test pieces are 8 inches long, and in some cases were cooled artificially. The results are compared with those obtained in a screw testing machine. In many particulars the results obtained conflict with generally received opinions, especially in the fact that the elongations were invariably materially increased by a suddenly applied load. Some sudden fractures showed a fine granular or silky appearance. Some kinds of iron are materially affected by the temperature, others but very slightly so. Also in some instances a small load suddenly applied caused a permanent set. An interesting test was made with the bolts used in the machine for transmitting the shock to the specimen. In a tensile machine there was nothing to indicate that the quality of the metal was impaired, but, in the impact machine, its ultimate strength, reduction of area, and elongation were only about a half of what they should have been. The author then discusses the reason why the elongation increases with suddenly applied loads, whilst at the same time the elastic limit

* *Comptes Rendus de l'Académie des Sciences*, vol. cxviii. pp. 418-421.

† *Proceedings of the Engineers' Society of Western Pennsylvania*, vol. ix. No. 6, pp. 14-45.

diminishes. It is considered that the elongation is a time function, since the elongation increases as the time diminishes in the screw machine, although the ultimate resistance remains the same. In the impact tests the energy is partly used in heating the specimen, and is not stored up in it as potential energy, so that on the release of the stress the test piece will not return to its previous length. That is, the conservation of energy accounts for the reduction of the elastic limit. The numerical results of the tests are given in a large number of tables.

The Relation between Stress and Strain.—Some experiments on the relation between uniform stress and permanent strain in wrought iron and steel have been made by T. E. Stanton.* Stress-strain diagrams are given for wrought iron bars:—(a) loaded uniformly from zero, (b) initial stress of 16 tons with increase of load every 20 minutes, (c) initial stress of 16 tons kept constant for 18 hours, (d) initial stress of 16·7 tons kept constant for 46 hours. The hardening effect of time is shown in these diagrams. Next a number of similar bars were loaded, with varying stresses applied uniformly in one minute, and maintained for 30 minutes, after which the strain was observed. The relation between stress and permanent strain was found to be $p = Ce^k$, where p is the stress, and e the permanent strain. C is a constant lying between 39·25 and 39·49 tons. By plotting the logarithms of p and e ordinates and abscissæ the value of k was found to be $\frac{1}{4}$ for some bars of mild steel, with a time stress of 30 minutes. The details of these several tests are given.

The Deformation of Metals under Pressure.—In a note on the distribution of deformations in metals submitted to stress, L. Hartmann † gives the results drawn from experiments made by the technical section of the Artillery. The deformation of bodies subjected to loads above their elastic limit does not progress uniformly through the body, but is divided into regularly distributed zones, of which the traces on the free surfaces are straight or curved lines regularly distributed. These zones are separated by non-deformed regions. In tensile tests, the pieces show two sets of parallel lines symmetrically placed, and always inclined at an angle of over 45°. The lines increase in number, and the stricture of the bar occurs where these are most numerous. In square bars there are

* *Memoirs and Proceedings of the Manchester Literary and Philosophical Society*, vol. viii. pp. 2-10.

† *Comptes Rendus de l'Académie des Sciences*, vol. cxviii. pp. 520-522.

straight lines, in cylindrical bars these lines are of helical form. Under compression, bending, or on forcing the metal through a die to form a cup-shaped article, two series of lines are found to occur. If the metal is attacked by acid while under stress, the action is greatest on these lines and least in the intermediate spaces, so that the elastic force developed at each point may be studied. The same procedure of attack by acid may be used with hardened steel articles.

In commenting on the above, F. Osmond * shows that the effect of acid has been noted by Werth and himself, and attributed to two causes. The first is the increase in the number of surfaces of attack by the dislocation of the surface; and the second is the partial formation of an allotropic modification under stress exceeding the elastic limit. Whatever the explanation, worked metal is more easily attacked than annealed metal. The author has also shown microscopically that by rolling at comparatively low temperatures, a banded structure is formed in the iron with alternately compact and porous layers. This is accentuated by hardening. The investigations of Carus Wilson on the striation of test pieces and their method of breaking is also referred to.

In a subsequent note, L. Hartmann † states that the laws of deformation mentioned above, apply also in case of percussion. This has been verified in several instances by him. He does not use the chemical methods referred to by Osmond, but purely mechanical methods.

Testing-Machinery.—Professor Tetmajer ‡ describes the testing laboratory connected with the Polytechnic School at Zürich. A Werder testing machine was erected in 1866, and the improvements which have gradually been introduced since then are described by the author. A new building containing twenty rooms has now been erected, and partially fitted, at a cost of £12,500. The plant includes two 100-ton testing machines and one 25-ton testing machine; [three hydraulic presses of 120, 20, and 2 tons capacity respectively; and a number of smaller testing machines for various purposes. In the thirteen years 1880–1892, 105,630 tests of various substances have been made at this laboratory; but these tests included not only tests of metals but also of building stone, cements, wood, and other materials. Indeed only 13,176 are specifically grouped under the heading “metals.” The aim and method of working of such a laboratory are discussed, and reference is made to the existence of similar laboratories elsewhere. The

* *Comptes Rendus de l'Académie des Sciences*, vol. cxviii. pp. 650–652.

† *Ibid.*, p. 738.

‡ *Stahl und Eisen*, vol. xlii. pp. 1090–1093.

two 100-ton testing machines erected at the Swiss laboratory are the one on the Werder system and the other on that of Pohlmeier.

T. Hudson Beare* describes the mechanical engineering laboratory at University College, London. The large testing machine, made by Greenwood & Batley, is of the horizontal type, capable of exerting a maximum pull of 100,000 lbs.

An illustrated description has been published† of a large hydraulic testing machine, the property of the Phoenix Iron Company, of Pennsylvania. It was designed for testing eye-bars, bridge members, columns, and other sorts of material. The full capacity of the machine is 2,160,000 lbs. Allowance being made for a stretch of 17 per cent. in parallel sections, it is possible to break an eye-bar 50 feet in length.

Tests of Crucible Steel.—H. Wedding‡ gives a large number of tests of materials composed of crucible steel, and of various brands of Dannemora and Dora metal. The results were comprised within the following limits:—

Limit of Elasticity. Tons per Sq. Inch.	Tensile Strength. Tons per Sq. Inch.	Elongation per Cent.	Reduction of Area per Cent.
22·9—39·8	43·0—65·0	36·0—3·2	47·0—3·8

The elongation within the limit of elasticity reached a maximum of 0·2904 per cent. in the case of a steel having a tensile strength of 61·3 tons per square inch. Figures for the modulus of elasticity are also given.

The same author§ gives the following results of tensile tests of steel products manufactured by Krupp, of Essen:—

Material.	Limit of Elasticity. Tons per Square Inch.	Tensile Strength. Tons per Square Inch.	Elongation per Cent.	Reduction of Area per Cent.
Ship frame	13·46	26·35	28·4	58·0
" "	14·03	27·30	27·3	54·5
" "	14·73	28·89	22·0	50·0
Wheel " . . . .	.....	23·43	31·0	60·9
" "	11·75—14·73	24·89—29·08	34·2—24·0	59·0—57·1
Centrifugal machine .	19·05	31·75	25·0	.....

Tests of Steel Rails.—M. White|| gives the results of some falling-weight tests of steel rails. The rails were placed 3 feet between

* *Journal of the Royal Institute of British Architects*, 3rd series, vol. i. pp. 290-294.

† *Engineering and Mining Journal*, vol. lvii. p. 5.

‡ *Stahl und Eisen*, vol. xlii. pp. 1031-1032.

§ *Ibid.*, pp. 838-840.

|| *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlii. p. 20.

supports. They were of the 70 lb. type, and the falling-weight weighed 1 ton. The results were as follows for rails containing 0.40 and 0.65 per cent. of carbon :—

Carbon. Per Cent.	Drop. Feet.	Deflection Produced. Inches.
0.40	10	1½
0.65	10	1½
0.40	15	2½
0.65	15	1½
0.40	20	3½
0.65	20	2½

Classification of Steel Plates.—According to a prominent American manufacturer, the classification of steel plates as set forth by manufacturers is misleading. It is evident that some uniformity should be adhered to, and that the grades should be simple and that each should carry requirements such as will ensure only first-class quality. The following appear to be clear and well-defined :—

	Fire-Box Steel.	Flange Steel.
Tensile strength, lbs. per square inch	54,000 to 60,000	54,000 to 62,000
Elastic limit, per cent.	50 to 60	50
Elongation in 8 inches, per cent.	27 to 30	25 to 28
Reduction of area per cent.	55 to 60	50 to 55

Shell steel should have a tensile strength of 56,000 to 64,000 lbs. per square inch, and tank-steel a tensile strength of about 60,000 lbs. per square inch.*

The Soundness and Working Qualities of Crucible Steel.—

F. Korb and T. Turner† discuss the soundness and working qualities of crucible steel. Attention is first given to the dissolved gases and the production of blow-holes, various authorities being freely quoted, and the action of silicon and other additions, together with the influence of pressure and other physical properties, being dealt with. Piping is due to contraction, but is obviated by feeding the casting with molten metal, the Sheffield practice of feeding being described. Crucible steel is

* *Iron Age*, vol. lli. p. 978.

† Paper read before the Mason College Engineering Society, 1893; *Industries and Iron*, vol. xvi. pp. 217-218.

then compared with open-hearth and Bessemer steels, and the effect of carbon is described. Burning of steel is ascribed to oxidation and the pernicious results of simple over-heating to the partial fusion of some of the constituents of steel, which has been shown by microscopic investigation to be of composite structure. Steel is also spoilt by too frequent heating, and this may be caused by absorption of the furnace gases and by partial oxidation. The purity of the steel affects its welding properties as an excess of impurities reduces the difference between the forging and melting temperatures, and within these limits such steel is red-short and brittle, the material being a mixture of which the more impure particles are partly or completely fused and enclosed in a network of unfused material.

The Working of Mild Steel.—J. Nodder* discusses the dangerous working heat of mild steel and the effect of annealing and air cooling, especially with reference to marine work, such as flanged boiler fronts, combustion chamber plates, tube plates and furnaces. For internal work, Admiralty practice demands that the tensile strength shall not exceed 26 tons tensile strength, while the shells and flanged fronts may be between 26 and 30 tons. The dangerous heat for working is placed at about 400° Fahr., but some experimenters hold that higher temperatures are dangerous. Failures of tube plates have often been ascribed to over annealing and air cooling. Unequal heating, especially between 400° and 600° Fahr., produces conditions that require careful annealing.

The Influence of Silicon on Iron.—E. Kirk† states that the effect of silicon on iron is to render it soft, and that in excess it reduces the transverse and tensile strength. It prevents chilling, and for this reason it is used in stove and other light castings. The amount that should be present depends on the amount of other elements in the iron. For heavy work, requiring great strength, no silicon should be present. For light machinery, from a half to 1 per cent. may be present, and for stove castings, 2 to 3 per cent. A larger amount reduces the strength too much, and injures its fluidity in the mould. Much cheap silicon iron produced in the Southern States is used in America for making stoves, and often too much of these softening materials is employed, so that the castings frequently break during transit, and do not wear well.

* Paper read before the Sheffield Society of Engineers; *Industries and Iron*, vol. xvi. p. 343.

† Paper read before the Philadelphia Foundrymen's Association; *Industries and Iron*, vol. xvi. p. 304.

The Use of Molybdenum in Steel Manufacture.—Molybdenum imparts great hardness to steel—a steel containing 2 per cent. of this element being described as extremely hard, of a silvery-white colour, and velvety fracture. Originally the molybdenum was made from the sulphide in the form of a ferro-molybdenum containing 10 per cent. of molybdenum, but it was found to retain sulphur and phosphorus. The metal itself, from 96 to 98 per cent. fine, the remainder being combined carbon, was produced by the action of carbon on calcium molybdate.*

The Alloys of Aluminium and Iron.—K. Styffe † observes that an addition of 0.25 per cent of aluminium to white pig iron or to high carbon steel tends, like silicon, though in a greater degree, to convert a portion of the combined carbon into the graphitic form, and thus, for instance, to render castings not only dense, but more regular in character, less brittle, and easier to work. If, however, white pig iron is to be converted into grey, an addition of at least 0.75 per cent. of aluminium is required. Malleable iron and steel are made somewhat harder and stronger by the addition of a small quantity of aluminium, provided that the percentage so added does not exceed that last given—0.75. Still, the percentage may sometimes be allowed to reach even 2 or more without deleteriously affecting the extensibility of the metal to any serious extent. If the percentage exceeds 5, then the iron alloys become more or less brittle. Such alloys appear useless, except as additions to iron or steel in the place of pure aluminium.

Alloys of Nickel and Iron.—F. Osmond ‡ gives a note on some of the iron nickel alloys. Analyses of nine specimens by Hadfield are given, and the points of transformation for these are noted. The appearance of magnetic properties on cooling is referred to, and the effect of this change on the mechanical properties is described.

Use of Steel for Structural Purposes.—A. Vávra § discusses the value of soft Bessemer ingot iron of Bohemian origin as a material for structural purposes. The Austrian Ministry for the Interior having raised the question as to whether or no basic Bessemer metal is better

* *Stahl und Eisen*, vol. xlii. p. 717.

† *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xli. pp. 536; compare *Journal of the Iron and Steel Institute*, 1893, No. II. p. 485.

‡ *Comptes Rendus de l'Académie des Sciences*, vol. cxviii. pp. 532–534.

§ *Berg- und Hüttenmännisches Jahrbuch der k. k. Bergakademien*, vol. xli. pp. 448–540.

than weld iron for bridge construction purposes, a series of experiments was made at the Kladno Steelworks with a view to elucidate this question. The results of these are now discussed by the author.

The iron ores in use are brown iron ores, and others described as chamoisite, from the ore deposit near Nucic. This latter class of ore in its uncalcined condition has approximately the composition—

Iron.	Silica.	Alumina.	Lime.	Manganese.
36	14	7	2	1·5

together with 2·5 per cent. of phosphoric anhydride, and 0·4 per cent. of sulphur. These ores are always calcined before being charged into the blast-furnace. The loss on calcining is about 22 per cent. The brown ore forms the upper portion of the chamoisite deposit. It is mined at Jinocan, and is not subjected to calcination. It contains—

Iron.	Silica.	Alumina.	Phosphorus.
32 to 42	16	8	2·5

together with some 4 per cent. of lime and magnesia and no sulphur.

Hot-blast coke pig iron is produced from these ores in three furnaces, all 50 feet in height, but varying in cubic capacity from 5156 to 7204 cubic feet. The outturn from the furnaces is respectively 62, 44, and 42 tons.

Silesian coke is used, which contains 8 per cent. of ash, and from 3 to 5 of moisture. Limestone from Beraun is used as flux. The temperature of the blast varies from 475° to 525° C.

The composition is given of the blast-furnace charges in the production of the pig iron used in these experiments. The metal produced contained :—

Carbon.	Phosphorus.	Manganese.	Silicon.	Sulphur.
3·50	2·32	0·38	0·17	0·04

In the basic Bessemer process as used at Kladno, care is taken in the elimination of the phosphorus to pass through the metal a very carefully regulated quantity of air. The end of the carbon stage is determined by the use of a spectroscope. The quantity of air is regulated by the use of a definite number of blowing engine revolutions for each period of the charge. After this number has been exceeded, the engine is stopped and the converter turned down, the iron being then completely decarburised and dephosphorised. The usual duration of a blow is above fourteen minutes. The question of turning down the converter, pouring into the ladle, and subsequently rolling into shapes, is next considered.

The methods of testing the various shapes is also given, and the testing-machine used is described. In the case of these experiments it was a Mohr and Federhaft machine intended for a maximum stress of 50 tons. The question of the breaking-down point is considered, and it is pointed out that basic Bessemer metal and open-hearth metal show such different behaviour at this point, that it affords a ready method of distinguishing the one from the other. The results of the various mechanical tests are shown in tabular form.

The next point considered is that of the homogeneity of the metal as regards its physical properties, and numerous tests of the metal were made both in the form of ingots and in other forms. They showed that the upper part of a basic Bessemer ingot is composed of somewhat harder metal than the lower part, the limit of elasticity showing a gradual rise from the bottom of the ingot upwards. After rolling, the metal does not show any different properties other than those to be accounted for by the difference in the composition of the metal rolled. As to the regularity in composition of the ingots of a cast among themselves, it is shown that the ingots first cast, in the case of a basic Bessemer blow, show a limit of elasticity lower to the extent of about 10 per cent. than do the ingots which are subsequently cast. It is pointed out, that in the case of large converter charges, it is best not to use for structural purposes the first and last cast ingots, but to place these on one side, and to use only the middle portion of the charge poured. Every charge, too, should be considered quite apart from each succeeding or preceding charge, as its composition may be very different. The various test pieces, however, though carefully examined, showed much homogeneity, and it may be concluded from this that the basic Bessemer metal experimented with contained no dangerous blow-holes or incompletely converted metal.

A series of analyses were made of the heads and bottoms of a number of ingots, and it was found that there was no difference in the composition, which averaged both for the heads and bottoms :—

Carbon.	Manganese.	Phosphorus.	Sulphur.
0·068	0·215	0·019	0·020

Check analyses made at Prague showed, however—

Carbon.	Manganese.	Phosphorus.	Silicon.
0·13	0·13	0·02	0·03

The question of the physical tests is then again gone into, it being shown that drilling increases the strength of a test piece when compared with punching, although the rimming out the punched holes led to results which were even better than those obtained from the

drilled test pieces. The questions of annealing and of hardening are passed in review, and it is shown that the weld in a bar is its weakest part. The action of a "blue" heat is shown, and then a series of tests are given which were made to ascertain whether basic Bessemer metal becomes fragile either when exposed to severe cold or to the ordinary or elevated temperatures. It was never found to be red-short, but was extremely brittle at a blue-heat, and only comparatively slightly brittle at very low temperatures. Bending tests of bars, and tensile tests of riveted material are also shown.

The results of all the tests made at the Kladno Works are considered as indicating that very soft basic Bessemer metal, showing a tensile strength of from 51,200 lbs. per square inch to 59,700 lbs., is the best kind of ingot metal for bridge construction purposes, and the various characteristics shown by the metal when under test are referred to in proof of this opinion. The commission also decided that other kinds of Bohemian steel were suitable for the same purpose.

Tests of Armour Plate.—In the First Lord of the Admiralty's explanatory statement * accompanying the Naval Estimates for 1894-95, it is stated that the past year has been remarkable for the results obtained from experiments conducted with steel armour treated by the "Harvey" process. Armour plates supplied by four firms have been tested by and for the Admiralty. The investigation has been most thorough and extensive, and, as a result, orders have been given for Harveeyed steel armour for the *Renown*, *Majestic*, and *Magnificent*. In the course of experiments the use of nickel as an alloy of steel for the purposes of armour plates has been fully tested. It has been established that Harveeyed plates without nickel in the steel show resistance to modern projectiles as great as any hitherto obtained when nickel was combined with steel in plates also treated by the Harvey process. The consequence of adopting this new system will be a great saving in cost for a given defence. By means of these improvements the power of defence obtainable with certain thicknesses and weights of armour has been very greatly increased, and this circumstance must considerably affect the designs of battleships to be laid down in the future.

Major General R. Wille† traces the development of the use of nickel steel for armour plates and for ordnance, and gives details of the results obtained.

* *The Times*, March 16, 1894.

† *Glaser's Annalen für Gewerbe und Bauwesen*, 1893, p. 41.

H. Wedding * states that armour plates manufactured by the Bethlehem Steelworks for the United States Government were made from raw material, containing $3\frac{1}{2}$ per cent. of nickel, produced by the open-hearth process. The upper end of the ingot is removed to the extent of at least 30 per cent. of the total length of the ingot. The tensile strength of the metal must be at least 65,000 lbs. per square inch, with 12 per cent. elongation, or, if the plates have been oil hardened, 75,000 lbs., with 10 per cent. elongation. At the Bethlehem Works there is now in active operation a 14,000-ton hydraulic press.

The various armour trials of importance during the past year are fully dealt with by Captain Orde Browne,† and illustrations of many of the plates are also given. The plates made by various manufacturers are also compared, and the great success that has attended the Bethlehem plates is pointed out. Distinct advantages appear to be obtained by discarding nickel in plates treated by the Harvey process, as the resisting power against penetration is greater although the toughness is less. The treated plate without nickel can also be drilled and worked more easily. Amongst the trials described are those with nickel and Harveyed plates at Texel, Indianhead, Ochta, and Shoburness. Alterations have recently been made in systems for recording the power of both armour and guns, and these are described, together with other particulars of ordnance and allied matters.

The trials at Texel in August 1893 were made with plates by six makers. All the plates were 6 feet 7 inches by 4 feet 11 inches, and were 5·9 inches in thickness, and weighed about 3·5 tons each. They were attacked by a 4·72-inch gun firing steel projectiles of 57·3 lbs., with a charge of 14·8 to 23·4 lbs. of powder, so as to give a striking velocity of 1444 to 1881 foot seconds. The plates made by Vickers, Cammell, and Brown were Harveyed, Krupp's and Schneider's plates had hardened faces, and the St. Chamond plate was not specially treated. The Vickers plate, after five rounds, was broken into three pieces, but the skin at the back was uninjured. This was the only plate that did not let the shot through. All the other plates were penetrated by the projectiles having the higher velocities, but were not broken on the face to the same extent. Altogether, all the plates were good.‡

A Harveyed Cammell plate, after sustaining the usual attack of five 6-inch projectiles, was fired at twice with Holtzer steel projectiles of 380

* *Stahl und Eisen*, vol. xiii. p. 1032.

† *Naval Annual*, 1894, pp. 357-420.

‡ *The Engineer*, vol. lxxvii. pp. 44-46, with illustrations.

lbs. The plate was 8 by 6 feet by $10\frac{1}{2}$ inches. The striking velocities were 1808 and 1948 foot seconds. The plate was broken by both rounds, and the point of the second shot projected 18 inches from the back of the plate. This trial was at Shoeburyness in August last.*

Trials also took place at Pola, in October and November, with four nickel steel plates from Dillingen, Vickers, Cammell, and Witkowitz, a Harveyed plate by Vickers, and a plate with hardened face by Krupp. The plates were 5.9 by 7.87 feet by 10.6 inches, and were attacked by four rounds from a 5.9-inch gun firing a steel projectile of 112.4 lbs. The striking velocity was about 1980 foot seconds. A fifth round was fired at the centre from a 9.4-inch gun with a steel projectile of 474 lbs., and striking velocity of 1417 foot seconds. The general result was that the Vickers and the Witkowitz plate fulfilled the condition of keeping out the smaller shot. The former was fractured by the larger shot while the latter was not, nor did it let it perforate.†

C. E. Ellis ‡ discusses recent experiments in armour, in view of the latest improvements that have been made in furnishing plates better able to cope with armour-piercing forged steel projectiles. The recent history of the subject is reviewed, accounts being given of trials with all-steel plates, with compound steel plates, with plates treated by Tresidder's process, and with plates treated by the latest development of this process by Harvey, whether or not containing nickel. The results obtained by the Harveyed plates are considered as a whole, no attempt being made to compare the productions of different makers, and the British trials are chiefly relied upon for this purpose. In America, the process is generally considered best when applied to nickel-steel plates, but owing to the cost of nickel in this country much attention has been directed to the process as applied to all steel plates, with the result of proving the reverse of the theory held in the United States. There may be, perhaps, a slightly greater tendency to crack in all-steel plates, but this is more than compensated for by the superior resistance to penetration. Besides this, the treated nickel-steel plates are almost impossible to machine. Some doubts have been expressed as to whether curved and twisted plates can be treated without warping them, but this has been successfully done by the author and others. A special characteristic of this kind of plate is the extraordinary resistance given to shot by small fragments of plate only. As an appendix, the author gives the results

* *The Engineer*, vol. lxxvii, p. 119.

† *Ibid.*

‡ Paper read before the Institute of Naval Architects, 1894; *Engineering*, vol. lvii, pp. 465, 530, 595.

of some thirty recent trials in tabular form, showing the maker, kind and size of plate, particulars of the attack, and the result both on the plate and on the shot.

Test of Projectiles.—An interesting proof of armour-piercing shot manufactured by T. Firth & Sons, of Sheffield, has been made at Shoe-buryness.* One hundred and sixty shot, 9·2 inches in diameter, weighing 380 lbs. each, were presented by the firm for reception tests, and two projectiles were selected at random for the proof. The first was fired with a striking velocity of 1958 feet per second, against a 14-inch compound plate. This was successful in an extraordinary degree, the shot passing entirely through the centre of the plate, then through 4 feet of oak backing, and burying itself in a heap of sand at the rear. When recovered, the shot showed no cracks, and was practically undamaged beyond a slight bulge near the front band, and total shortening of the projectile on a length of 29 inches was only $\frac{3}{8}$ inch. This round was considered so satisfactory that it was not necessary to fire a second shot, and the whole of the lot was accepted.

* *Engineering*, vol. lvii. p. 460.

CHEMICAL PROPERTIES.

Nitride of Iron.—G. I. Fowler* describes his researches on the composition of nitride of iron, his results agreeing with those of Stahlschmidt in showing that only one nitride exists, and that it has the composition Fe_2N . To prepare this substance, iron, reduced from its hydrate by hydrogen, is exposed to a current of ammonia gas at a temperature a little above that of melting lead until its weight is constant. The nitrogen is determined by dissolving the substance in hydrochloric acid, evaporating with platinum chloride, and weighing the ammonium-platinum-chloride obtained. The hydrogen given off on solution of the substance in sulphuric acid is measured. The iron is determined by ignition and weighing as oxide, and by solution in sulphuric acid and titration with permanganate.

The nitride is also formed by heating iron amalgam, or chloride or bromide of iron in nitrogen. The compound is a grey powder which is feebly magnetic, and is stable up to the boiling point of sulphur. Calorimetric experiments show that this substance is formed with the evolution of about three calories.

In the discussion, Allen stated that he had determined traces of nitrogen in iron by dissolving one gramme of the metal in hydrochloric acid, adding pure lime in excess and distilling. The ammonia liberated is determined in the usual way by Nesslerising.

Segregation in Iron and Steel.—In the discussion† on some papers‡ on segregation in iron and steel ingots, Professor T. M. Drown describes some investigations on the purification of water by freezing as bearing on the subject. The impurities are concentrated into the last part of the water frozen.

* Paper read at the Nottingham Meeting of the British Association; *Chemical News*, vol. lxviii, pp. 152-153.

† *Transactions of the American Institute of Mining Engineers* (advance proof).

‡ *Journal of the Iron and Steel Institute*, 1893, No. II. p. 521.

R. A. Hadfield confirms Pourcel's statement that segregation may occur in other than thick sections. He finds, however, that in the manufacture of chromium steel at Sheffield, there is very little variation in the composition throughout the product. This also applies to the manufacture of manganese steel. Segregation must not be confounded with imperfect mixing.

W. J. Keep enlarges on the subject of segregation in cast iron. In making large thin castings, small drops or beads sometimes liquate out. These are of white iron, and an analysis of them, compared with the grey iron of the castings, gave results as follows:—

	Carbon.	Silicon.	Manganese.	Sulphur.	Phosphorus.
White . . .	2.64	2.47	0.91	0.042	1.00
Grey . . .	3.01	2.48	0.90	0.035	0.95

Illustrations are then given of a number of sections of Swedish pigs which show a stratification of white and grey iron, and also of a number of castings in which the white and grey iron is irregularly distributed, with particulars as to the way in which they were cast, whether in chills or otherwise.

T. Bergendal states that the sharpness of the division between the white and grey iron depends on the composition of the slag, more basic slags giving sharper demarcation.

Professor E. D. Campbell gives an exception to the general rule, that impurities are concentrated in those parts of the casting which remain fluid longest. In some cast iron wheels, the percentages of silicon, phosphorus, and manganese were all higher in the rim than in the hub, showing local segregation induced by the chilling. The phenomena of diffusion are closely allied to those of segregation. The diffusion of carbon from one piece of iron to another has been held to indicate that it exists in a free state in the metal. This theory may be disproved if it is found that compounds such as the sulphide or phosphide of iron will diffuse through a mass of the metal. Experiments on this subject are being carried out at the Michigan University, and are described. Holes bored in a number of bars of iron were filled with sulphide of iron and heated to various temperatures. In some cases the holes were plugged, and in other cases more sulphide was added after heating. In none of the experiments was the percentage of sulphur in the iron increased, although the sulphide had disappeared.

H. D. Hibbard ascribes the hard spots found in machining castings and forgings to local segregation, instead of to unmixed particles of

ferro-manganese or spiegeleisen. In forgings imperfectly welded, blow-holes often occur near these hard spots.

A. C. Cunningham discusses the relationship of segregation to the manufacturer's specifications. As long as chemical limitations are determined by ladle analysis alone, special attention to the temperature of casting and working cannot be expected beyond that necessary to protect the manufacturer. In most instances, rivet holes are punched in structural material where segregation is lightest, but in some instances segregation is a positive danger. Now that the size of pieces is approaching the limit of the capacity of works, as for instance, in eye-bars, the failure of their ends may be ascribed to segregation instead of to imperfect working. The knowledge of the laws of segregation enables the tests to be taken from the most favourable parts, and these may be further improved by special local treatment. A specification is then given, the terms of which are thought to provide for this feature, and to still leave room for the manufacturer to work to the best advantage :—

	Phosphorus.	Sulphur.
Samples from steel when poured not to exceed . . .	0·06	0·06
Drillings from any part of finished material not to exceed	0·07	0·06

The use of new alloys, as suggested by Pourcel, does not deal with phosphorus and sulphur. Several analyses are then given of drillings taken from various parts of plates and axles, to show the effect of segregation on the tensile tests, details of which are also given.

A. A. Stevenson and R. Kent, as the result of a large number of tests, are of opinion that segregation and piping in ingots are the causes of by far the larger percentage of failures of steel tires. These may therefore be reduced by cropping the ingots. Carbon, phosphorus, and sulphur are the elements most liable to segregation, but as only small ingots were used, that of manganese and silicon was not apparent. Etching shows very clearly whether segregation has taken place, those parts affected being more porous or granular in appearance. In every case the results confirm those deduced from tensile tests. Reproductions of etched sections are given, both of ingots and tires, and also eight tables showing in detail analyses from various parts, and the tensile tests.

P. H. Dudley remarks that many rails which broke in cold weather were found to be top rails from the ingot.

The Influence of Oxygen on Iron.—P. Gladky * points out that

* *Stahl und Eisen*, vol. xiii. pp. 1094–1096; compare *Journal of the Iron and Steel Institute*, 1893, No. I. p. 392.

1894.—i.

the bad qualities of iron are often attributed to the presence of sulphur, or some other impurity, when it is probably oxygen that is causing the deleterious effect. In the Urals, he points out, it is weld iron that is the most important product even now, and the works, with a view to the production of heavy products and for financial reasons, endeavour to produce the largest sized blooms they can. In consequence of this, it frequently happens that although the raw materials employed may be of remarkable purity, yet the quality of the metal produced is bad, and the metal red-short. This is probably due to the action of oxygen in some form. Professor Ledebur, the author observes, considers that it is only in ingot metal that oxygen produces red-shortness, the oxygen existing in this case as dissolved ferrous oxide, but that any oxygen found in weld iron occurs as slag or scale, and that a considerable quantity of these can be present without seriously affecting the metal. Gladky differs from this view, and holds that if ferrous oxide is present in weld or ingot iron it is disseminated and not dissolved, and that this oxidation is more frequent in weld iron than it is in ingot metal.

Sulphur in Iron.—Referring to the papers on this subject which have been read before the Iron and Steel Institute by J. E. Stead and E. H. Saniter,* K. Hilgenstock † observes that hitherto it has been assumed that desulphurisation by the action of lime was only possible at a high temperature, and in the presence of a reducing agent, such as carbon, the reaction being according to the formula:— $\text{FeS} + \text{CaO} + \text{C} = \text{Fe} + \text{CaS} + \text{CO}$. The Rollet method must be mentioned in this connection. This process consists in melting down the iron to be desulphurised in a cupola provided with a basic magnesia lining. The action of sulphur on iron is to produce brittleness at a red heat, though at a white heat this action is scarcely observed, and it is absent when the metal is cold. The permissible limit for sulphur is 0.02 in the case of weld iron, while for ingot metal Ledebur places the limit at 0.10 per cent. Experiments made by Wasum coincide in their results with these. He found that 0.1 per cent. of sulphur did not exert any deleterious result on Bessemer metal, while with 0.15 to 0.16 per cent. red-shortness became probable. On the other hand, the weldability of the metal is endangered by even 0.06 per cent. of sulphur. Sulphur passes into pig iron either from the ores or from the fuel. In both of these iron pyrites is found, and occasionally copper pyrites is also present. Neither ores nor fuel can

* *Journal of the Iron and Steel Institute*, 1893, No. I. p. 299.

† "*Der Schwefel im Eisen*," Erlangen, 1893.

be completely freed from sulphur by the methods of preparation that are in use. Coke usually contains considerable quantities of sulphur, Muck, in the case of Westphalian coke, finding the percentage to average from 1 to 1.5. Indeed it seldom exceeds 1.8 per cent., and rarely falls below 0.8 per cent. It follows from this that in every blast-furnace making 100 tons of pig iron per day, 1 ton of sulphur is charged in daily. This sulphur of the coke is more dangerous than that of the ore, as the coke carries it down unchanged to the tuyere level. If the slag that is being produced is not strongly basic, or if the temperature is low and the reduction of manganese but slight, then a pig iron is apt to be produced that is high in sulphur. This also occurs in the case of the open-hearth. Here gas-firing being used, the sulphur of the coal passes over the bath of metal in the form of sulphurous acid, sulphuretted hydrogen, or even silicon sulphide. The larger part of the sulphur is then absorbed by the molten metal. It is to this fact that the explanation must be looked for of the non-elimination of the sulphur from the metal under treatment in a basic-lined open-hearth.

The author gives the results of a series of experiments which show that manganese will desulphurise iron, the reaction being as follows:— $\text{FeS} + \text{Fe} + \text{Mn} = 2 \text{Fe} + \text{MnS}$. He refers to the well-known Hoerde process of desulphurisation by this method, and he gives partial analyses of two "bears," showing in the one instance 8.24 per cent. of manganese and 3.36 of sulphur, and in the other 8.47 of manganese and 2.73 of sulphur. In the first instance the mother metal contained 1.54 per cent. of manganese and 0.093 of sulphur. These "bears" were obtained when basic pig iron was run out of the ladle in which it was being taken to the converter. Berthier was probably the first to point out the action of manganese as a desulphurising agent, and Carow proved this afterwards as the result of numerous experiments. Various experiments are described which have reference to this question. Manganese sulphide is so extremely hard to fuse that it makes the metal under treatment pasty, by preventing the particles from running together, and the sulphide may even separate from the metal as a thick crust, which is mainly manganese sulphide, an analysis showing:—

MnS.	MnO.	FeO.	SiO ₂ .
85.75	9.11	4.74	0.70

It is certain that in the blast-furnace calcium sulphide forms in addition to the manganese sulphide, but the author considers it most improbable that the manganese silicate or the manganese oxide carries manganese

sulphide or ferrous sulphide into the slag. It is much more probable that the sulphide liquates out. Owing to the oxidising conditions, the presence of manganous oxide in sulphide slag is unavoidable. Manganese sulphide is thus insoluble in iron, while iron sulphide is soluble. That portion of sulphur which remains in the iron after the elimination of the larger part is in the form of suspended manganese sulphide. Consequently small quantities of sulphur are not dangerous, if an adequate percentage of manganese is present. The fact that the enrichment in sulphur of the heads of ingots is not accompanied by a similar increase in the percentage of manganese is probably due to the manganese being present in too small a quantity.

Manganese, then, is a very useful element for desulphurising purposes, the only objections possible to its use being that it increases the quantity of foreign elements alloyed with the iron, makes the slag more thin-fluid, and so, by rendering in the basic Bessemer process the dephosphorisation more difficult, may lead to the iron produced being harder than was desired.

The author next proceeds to consider the action of aluminium on iron sulphide. He shows by experiment that aluminium will decompose iron sulphide, an interesting point in connection with the experiment being the reduction of silicon from the walls of the crucible. The elimination of sulphur is very complete, an aluminium sulphide slag being produced. In this direction, nickel is without action, as was to be expected, in view of the fact that such a reaction would have been of an endothermic character, the formation of FeS yielding 23,750 calories, while that of NiS is only accompanied by an evolution of 19,370. Copper gives similar results. Chromium, on the other hand, is a desulphurising agent, though of a less active character than manganese. The addition of a ferro-chrome containing 38 per cent. of chromium and 3 of manganese to molten ferrous sulphide resulted in the formation of an iron alloy containing 10.56 per cent. of chromium, and only 0.037 per cent. of sulphur. The slag, which was carefully separated from the metal, contained—

Chromium.	Sulphur.	Iron.	Manganese.
14.96	14.35	31.42	1.44

The presence of ferrous sulphide in the slag tends to the assumption that chromium, as has been observed, is less active as a desulphuriser than is manganese.

Next, as to the action of silicon on ferrous sulphide, the author refers to Turner's experiments on this subject, showing that when ferro-silicon

and ferrous sulphide are fused together, there is no absorption of the sulphide by the alloy.

The next portion of the author's experiments consisted in ascertaining the action of sulphur in the form of sulphurous acid and sulphuretted hydrogen, on ferro-manganese containing 80 per cent. of manganese, and on basic pig iron which contained 2.5 per cent. of phosphorus, 1.5 of manganese, and 0.06 of sulphur. The metals were heated in a fine state of division in a Rose crucible and the gases passed over them, the two metals being treated simultaneously in the same crucible, only separated from each other by asbestos. The experiments showed that in this case also the manganese alloy absorbed sulphur more rapidly than the metal containing less manganese.

The action of oxides in absorbing gaseous sulphur was next investigated. Lime was a far stronger absorbent than magnesia, or than the oxides of manganese or iron at a dull red, while at a bright red heat lime and manganese are of equal value, and the oxide of manganese has become a much more powerful absorbent than either. These experiments relate to sulphuretted hydrogen. Other experiments, made with sulphurous anhydride, show that at a bright red heat lime is still a stronger absorbent than either of the other oxides. In this case magnesia appeared to be a very poor absorbent for the gas, and so, too, was ferric oxide, while manganese sesquioxide was nearly as powerful as lime.

The next series of experiments related to the action of carbon disulphide vapour. In this case lime and magnesia proved very poor absorbents, while the oxides of iron and manganese took up sulphur very readily, and, indeed, were practically converted into their respective sulphides.

The Corrosion of Iron.—The influence of some chemical agents in producing injury to iron and steel is discussed by W. Thomson.* The pitting of iron boilers is often produced by free sulphuric acid in the feed water, or by nitrites and nitrates in purified sewage. Zinc plates, tannate of soda, and other substances, aid in counteracting this effect. The action of different paints and varnishes in protecting the metal is also dealt with, and the author has found that red lead is the most efficient, in spite of its oxidising properties. This is because a thin skin of protective magnetic oxide is formed on the surface.

Some information regarding failures in cast-iron pipe, which have a bearing on its life, is given by G. Murdoch,† of the waterworks at St.

* *Transactions of the Manchester Association of Engineers*. 1893, pp. 245-269.

† *Engineering News*, New York, vol. xxxi. p. 15.

John, New Brunswick, in his report for 1892. The failures described occurred in pipes laid in mud, clay, and well-drained gravel, and were due to defects and air-holes in the pipes where the iron had corroded. These pipes had been in use for over thirty years. Neglecting accidents and defects of manufacture, the author is of opinion that the life of uncoated cast-iron pipes is practically indefinite.

Dr. Weber * discusses the causes which lead to the corrosion of iron pipes when laid in earth. He also refers to various cases in which such pipes used for the conduit of water have suffered perforation. Sulphuretted hydrogen, nitrates, and of course free acids, are important sources of deterioration. He proposes to bed the iron pipe in clay, or, better still, to place it inside a clay pipe. Cement is of less value as a coating, but the use of an asphalt varnish is attended with some success. Another material, which is described as manganese cement dissolved in varnish, is also stated to give good results as a protective coating for iron pipes.

O. Brown † illustrates a remarkable instance of the corrosion of an iron bar. The bands of rust extend over both the ends of the bar, giving it the appearance of being built up of layers of two different metals. Under test the bar, which is of best Yorkshire iron, gave the following results :—Tensile strength, 24·21 tons per square inch ; elongation on 8 inches, 28·4 per cent. ; contraction of area, 49·6 per cent. No traces of lamination were shown during the test, but some months after the bar was found in the condition illustrated, which seems to show that the bar really does consist of layers of slightly different chemical composition, of which those layers which have rusted are electro-negative to the remainder of the bar.

The Volatility of Manganese.—In a paper read before the Academy of Sciences in France, Professor S. Jordan described some experiments made by R. Lorenz and F. Heuesler, ‡ which confirm his previous statement that manganese can be volatilised at the temperatures existing in metallurgical furnaces. The experiments showed (1) that when a current of carbonic anhydride is passed over metallic manganese contained in a porcelain tube, and raised to a white heat, part of the gas is reduced, and part of the metal is volatilised ; (2) when the carbonic anhydride was replaced by carbonic oxide, there was still a volatilisation of a

* *Journal für Gasbeleuchtung und Wasserversorgung*, 1893, p. 552.

† *Engineering*, vol. lvii. p. 544.

‡ *Zeitschrift für anorganische Chemie*, vol. iii. pp. 225-229.

portion of the metal, and this was visible spectroscopically in the combustion of the gas at the end of the tube; (3) with a current of dry hydrogen identically the same results were obtained; while (4) in a current of nitrogen the volatilisation of the manganese was again observed, but the metal does not combine with nitrogen, as is the case with chromium. The results of the experiments point to the volatility of the metal being simply the effect of temperature.

CHEMICAL ANALYSIS.

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I.—ANALYSIS OF IRON AND STEEL.

Standard Methods of Analysis.—Dr. C. B. Dudley* discusses the necessity for standard methods of analysis of iron and steel. When chemists analyse identical samples with pure chemicals and disagree, the fault must be one of method. The adoption of standard methods would enable competent chemists to obtain strictly comparable results. Such methods would be revised when necessary, but should be regularly used until so revised. The work of the committee on international standards will produce valuable results, but their standards will not be a check on difference of methods. A method of analysis may have reciprocating errors, and give correct results on samples of one certain composition only. A chemist using such a method might agree with the standard sample, and yet be wrong on all samples of different composition. A further shortcoming of standard samples, as checks on methods of analysis, is found in the consideration that unless the standard contains carbon and other elements in the same state of combination in the steel in which it exists in all other samples analysed by the same method, it is not a check on the correctness of the method. A considerable amount of discussion ensued, in which several methods that have been proposed as standards were criticised.

Reference has already been made to some of the methods employed by J. Parry and J. J. Morgan.† In a series of articles‡ they have

* *Proceedings of the Engineers' Society of Western Pennsylvania*, vol. ix. pp. 35-36.

† *Journal of the Iron and Steel Institute*, 1893, No. I. p. 403; No. II. p. 440.

‡ *Industries*, 1893.

given the methods they adopt for the determination of silicon, phosphorus, carbon, sulphur, copper, tungsten, iron oxide, titanium, and manganese in steel. The silicon is best determined by dissolving in nitro-hydrochloric acid, and then either fusing the residue with potassium bisulphate, or treating it with a mixture of sulphuric and hydrofluoric acids. For rapid determinations the metal may be dissolved in dilute sulphuric acid, and the resulting residue filtered and ignited direct, not carrying the evaporation further than to the appearance of sulphuric acid fumes.

The phosphorus is determined by the molybdate method. The sample of metal dissolved weighs about 4 grammes, and the phosphorus is precipitated by the addition of 50 cubic centimetres of a solution obtained by dissolving 60 grammes of ammonium molybdate in one litre of water, adding 50 cubic centimetres of concentrated ammonia and a slight excess of nitric acid, the solution being allowed to stand for two days before use.

In the determination of the total carbon the authors dissolve 5 grammes of the iron in 120 cubic centimetres of a solution of 280 grammes of cupric-ammonium chloride in a litre of water, using a gentle heat to aid the solution, and adding more chloride if the solution becomes light in colour. After filtering through asbestos, the copper is dissolved by some of the cupric solution and hydrochloric acid, and the carbon oxidised by chromic-sulphuric acid, the gas evolved being passed, in the first instance, through a solution of silver sulphate in sulphuric acid, then through sulphuric acid and calcium chloride, and finally through a solution of 1 part of caustic potash in $1\frac{1}{2}$ part of water. To avoid loss, the caustic potash is followed by a tube filled half with soda-lime and half with calcium chloride. The combined carbon is determined by the ordinary colour test, and the graphite either by direct weighing after solution of silica by caustic potash, or by combustion with copper oxide.

Sulphur the authors determine either by the solution of the iron in nitro-hydrochloric acid, and precipitation by barium chloride, or by dissolving the iron in dilute sulphuric acid, and passing the gas evolved into a solution of copper sulphate. Copper is determined by evaporating the iron solution to dryness, taking up with hydrochloric acid, filtering the solution, diluting to 200 cubic centimetres, completely reducing with sodium sulphite, boiling off the excess of sulphurous acid, and then passing sulphuretted hydrogen through the solution until complete saturation results. The precipitate is filtered off, washed with sulphuretted hydrogen water, and then washed into a beaker by the aid of a wash-bottle. It is dissolved in nitric acid, diluted, filtered, and the copper precipitated

by caustic soda, the oxide being washed, ignited, and weighed in the ordinary manner. Another method consists in dissolving the iron in sulphuric acid, adding a little hyposulphite solution and boiling, filtering, dissolving the precipitate in nitro-hydrochloric acid evaporated with sulphuric acid, diluting, adding excess of ammonia, filtering, boiling of the ammonia, and precipitating the copper with hyposulphite in the ordinary way.

In the determination of the tungsten, the iron is dissolved in nitro-hydrochloric acid, evaporated, care being taken to avoid too high a temperature, taken up with hydrochloric acid, filtered. The tungstic acid is then dissolved in concentrated ammonia, evaporated, and heated to redness in a platinum dish, the residue, tungstic anhydride, being then weighed. Any oxide in the steel remains undissolved when the metal is dissolved in a hot solution of potassium bichromate and sulphuric acid. The solution is allowed to settle, decanted through a filter, the residue washed by decantation, heated with potash solution to dissolve the silica, filtered, washed, ignited, and weighed. Any titanium present in the steel remains in part in the silica residue, when the silicon is determined in the usual way. This residue is fused with potassium bisulphate, the fused mass extracted with water, and the solution added to the main bulk of the solution from which the silica had been separated by filtration. The ferric oxide it contains is then almost completely reduced by the use of sodium sulphite, the solution is almost neutralised with ammonia, and then treated with sodium acetate in the usual manner, the precipitate produced containing the titanous acid. This precipitate is fused with bisulphate, extracted with cold water, the ferric oxide reduced with sodium sulphite, the solution almost completely neutralised, boiled for 4 hours, and the separated titanous anhydride filtered, ignited, and weighed. Another method is also given.

In determining the manganese, the authors employ the ordinary ammonium-acetate, bromine method, the manganese oxide being ignited, weighed, and then redissolved in hydrochloric acid, and the iron contained in the precipitate re-precipitated with acetate, and the quantity found subtracted from the weight first found. A colorimetric method for the determination of the iron is also given, comparison being made with a standard solution of iron to which ammonium sulphocyanide has been added.

H. von Jüptner discusses the paper on the analysis of iron, read by W. Parker * before the American Institute of Mining Engineers, in

* *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xli. pp. 617-620.

which the results obtained by various analysts when analysing the same material are given and compared. The results showed remarkable differences. Other comparative analyses, which the author refers to, have been published by von Reis and by Kail and others, and he gives others which he himself has made. He makes various suggestions in connection with these, and considers that the errors are mainly due to the personal co-efficient and want of knowledge of the analyst. It is not advisable, he points out, to adopt any much-lauded new method, in preference to simpler methods, as every additional operation introduces new sources of error. It is better not to have too many different chemists employed, a large laboratory for several works being preferable to each small works having its own laboratory. Then, too, the so-called "average" samples are in themselves very important yet obscure causes of error.

C. B. Dudley and F. N. Pease* suggest the following as the permissible limits of error within which any analytical method should be accurate :—

C.	P.	S.	Si.	Mn.	Cu.
0·010	0·005	0·005	0·010	0·010	0·005

In addition, the method, if it is to be of commercial value, must be both rapid and easy, and it must yield regular results in the hands of different analysts.

The sub-committee appointed by the Committee on International Standards to consider the question of standard methods of analysis, have published their first report.† It was decided to forward circulars to iron and steel chemists, asking them for a brief outline of the methods that they prefer. The work of the committee will be confined to the recommendation of standard methods to be used as the basis of commercial transactions.

The Determination of Carbon.—A. Ledebur‡ has investigated the accuracy of the methods in general use for the determination of carbon in the different forms of cast iron and steel. The materials examined were :—

1. A mottled charcoal pig iron, containing 0·79 per cent. of silicon and 1·54 manganese.
2. A white pig iron, with 3·0 per cent. of manganese and 2 per cent. of phosphorus.
3. A crucible tool steel, with 0·11 per cent.

* *Journal of the American Chemical Society*, vol. xv. pp. 501-541.

† *Engineering and Mining Journal*, vol. lvii. p. 128.

‡ *Verhandlungen des Vereins für Beförderung des Gewerbfleißes*, vol. viii. pp. 280-319 ; *Minutes of Proceedings of the Institution of Civil Engineers*, vol. cxv. pp. 465-469.

of manganese and 0.12 per cent. of silicon. 4. A basic mild steel recarburised by Darby's process, with 0.54 per cent. of manganese. 5. A similar steel, with 0.56 per cent. of manganese. These two samples were distinguished as Darby steel, A and B.

The samples for analysis, with the exception of the white pig iron which was crushed in a steel mortar, were prepared in the form of drillings by a blunt drill free from grease. This form was selected as being best suited to the ordinary conditions of ironworks practice, while it allowed the ready detection and separation of foreign matters. It was also considered that methods giving good results with borings would be equally suitable with the metal in filings, while the reverse condition might not always be true.

The processes of determining total carbon examined were the following:—

1. *Direct Combustion with Oxygen.*—Three experiments upon grey pig iron continued for $3\frac{1}{2}$ hours in the first instance, and $6\frac{1}{4}$ hours in the second, and gave 3.254 and 2.872 per cent. of total carbon respectively. With longer continued heating, and the sample in filings instead of borings, probably more concordant results might have been obtained, but having regard to the ease with which mistakes may be made, the bulky character of the apparatus and the slowness of the operations, this method seems to be unsuited for practical use.

2. *Oxidation by Chromic and Sulphuric Acids.*—In this, known as Jüptner and Gmelin's method, the metal is dissolved with simultaneous oxidation of the carbon to carbon dioxide, by boiling it with a saturated solution of chromic acid, mixed with about twenty times its volume of strong sulphuric acid, for periods varying from 1 to 2 hours. Four experiments were made with grey pig iron, and two with tool steel, but the results were in all cases too low. This is due to the circumstance that there is invariably some hydrocarbon gas formed during the solution which escapes oxidation.

3. *Oxidation by Chromic and Sulphuric Acids with Combustion of Hydrocarbons.*—In this modification of the preceding method, which is due to Sarnström, the gases evolved from the dissolving vessel are passed through a heated tube containing cupric oxide, or a red-hot capillary tube of platinum, in order to decompose any hydrocarbons that may be formed. This, being one of the best methods in regard to accuracy, was subjected to numerous trials, with the apparatus modified in several different ways to meet particular cases of error. The results obtained with all the samples were about the same with either kind of supple-

mentary combustion ; but the author considers the platinum tube to be preferable to that with cupric oxide, as the latter requires frequent renewal, and takes a longer time to heat, fifteen to twenty, instead of one or two minutes. The time required for the complete analysis is from $\frac{3}{4}$ to 1 hour for the preliminary heating, followed by 2 to $2\frac{1}{2}$ hours continuous boiling, a rapid current of air being maintained through the apparatus without interruption. When the temperature of the air in the laboratory exceeded 20° C. (68° Fahrenheit), the proportion of carbon found appeared to diminish as the temperature rose. This was traced to the circumstance that the dried air used in driving the carbon dioxide out of the combustion apparatus into the potash bulbs, took up moisture from the potash solution which was not reabsorbed by the calcium-chloride tube at the end of the apparatus, and it was only by the addition of a supplementary tube with strong sulphuric acid that this source of error was avoided.

4. *Removal of Iron by Cupric Sulphate.*—This method was tried with cast iron, the action of the blue vitriol solution being continued from $4\frac{1}{2}$ to 7 hours, the separated carbon being subsequently oxidised by chromic and sulphuric acids. The results were too low, owing to loss of carbon as hydrocarbon gases, and therefore the experiments were not continued.

5. *Removal of Iron by Cupric Sulphate and Combustion of Hydrocarbons.*—This is a modification by Sarnström of the preceding method, an accessory combustion apparatus either by cupric oxide or heated platinum being used in method No. 3. The results were as a rule correct, though in some cases rather high, leading to the supposition that sulphur dioxide may have been formed by the action of the strong sulphuric acid upon metallic copper separated during the solution of the iron, but a long series of experiments with a view to determine this point led to no result.

6. *Removal of Iron by Cuprammonium Chloride.*—This method, introduced by M'Creath, was much used about ten years since, but the discovery of several sources of error, real or supposed, have led to its abandonment. When tried with cast iron it gave good results, but with steel was less satisfactory. In some cases the figures obtained were too high. This may be due to the sal-ammoniac, which, when made from ammonia derived from tar distilling, is apt to contain carbon. In any case, the results depend so much upon manipulation that the method cannot be recommended for general use.

7. *Removal of Iron by Dry Chlorine.*—In this method the sample contained in a porcelain boat is heated in a current of dried chlorine gas

until the whole of the iron is volatilised as ferric chloride, and the separated carbon remaining in the boat is subsequently oxidised by chromic and sulphuric acids. This, if properly conducted, is probably the most accurate of all the methods, but the author considers that the results may be too high if the carbon residue is burnt without being previously washed to remove traces of chloride remaining. And in the latter operation losses may easily occur, owing to the escape of finely divided carbon through the filter. For this reason the results obtained with grey cast iron are better than with white iron or steel, as in the latter the carbon, being separated in an extremely light form, is more readily carried away in the gaseous current, or by washing, than in the former, where it is mostly present in the denser form of graphite.

The general results of the investigation are contained in the following table, which gives the average figures obtained by each method and their extreme variations :—

Method.	Carbon per Cent.				
	Cast Iron.		Crucible Steel.	Darby Steel.	
	Grey.	White.		A.	B.
1. Combustion in oxygen—					
Average result	3.214	...	...	...	...
Extreme variation	0.643	...	...	...	...
2. Solution in chromic sulphuric acid alone—					
Average result	3.565	...	0.732	...	...
Extreme variation	0.418	...	0.045	...	...
3. Solution in chromic sulphuric acid and accessory combustion—					
a. With cupric oxide—					
Average result	3.955	3.225	0.870	0.555	0.391
Extreme variation	0.024	0.064	0.059	0.009	...
b. With platinum tube—					
Average result	3.871	3.248	0.859	0.550	0.380
Extreme variation	0.209	0.208	0.064	0.016	0.046
4. Solution of iron with cupric sulphate only—					
Average result	3.636	...	...	...	...
Extreme variation	0.237	...	...	...	...
5. Solution with cupric sulphate and accessory combustion—					
a. With cupric oxide—					
Average result	3.747	...	...	0.646	...
Extreme variation	0.182	...	...	0.033	...
b. With platinum tube					
Average result	3.760	3.387	0.903	0.664	...
Extreme variation	0.043	0.046	0.009	0.031	...
6. Solution with cuprammonium chloride—					
Average result	3.968	...	0.927	...	0.404
Extreme variation	0.236	...	...	...	0.026
7. Removal of iron by chlorine—					
Average result	3.999	3.282	0.869	0.593	0.368
Extreme variation	0.112	0.018	0.089	...	...

The grey pig iron of the previous experiments was examined by eight different methods for the determination of its contained graphite. In five of these hydrochloric acid was used as the solvent, at temperatures varying from 50° Centigrade to the boiling point, for periods ranging between one and twenty-four hours, the residue being washed with water, potash lye, alcohol, and ether, and dried at 100° to 120° Centigrade. In the remaining three, nitric acid was used, the residue being washed with water alone, but dried at different temperatures as before. The results obtained were too high when hydrochloric acid was used at a low temperature, as then the carbide, or semi-combined carbon, is not decomposed, and is ultimately burned with the graphite. This error is avoided by the use of nitric acid, which has the further advantage of dispensing with the troublesome washing with alcohol and ether. In either case it is necessary to dry the residue at a higher temperature than 100° Centigrade, or there may be a considerable error in excess.

The final combustion may be effected equally well with oxygen or chromic-sulphuric acid; the mean result obtained by the former was 2.745, and by the latter 2.749 per cent. A second portion of the memoir contains an investigation of the Eggertz process as applied to steel of different kinds, both as cast and when forged and rolled. This confirms generally the accuracy of the process and its applicability to practical uses. One sample of Bessemer steel behaved in a very anomalous manner, giving very irregular results both when examined alone and when used as a standard. This the author considers may have been caused by its being water-cooled before use, but the fact could not be established.

In his concluding remarks, the author considers that the two Sarnström methods Nos. 3 and 5, are to be recommended for general use; the former being best adapted for graphitic iron, and the second for other forms of iron and steel with combined carbon, which are not easily decomposed, except the iron be removed by copper sulphate. For check purposes the chlorine method is of great value.

The volumetric methods of determining carbon by measuring the carbon-dioxide produced, instead of weighing it, have not up to the present time proved sufficiently accurate for practical use, although it is not improbable that they may shortly be improved so as to be equal to the older methods.

Göttig* states that he made the following questions the basis of his work:—(1.) Under what circumstances, if any, is it possible to determine

* *Verhandlungen des Vereins für Beförderung des Gewerbfleisses*, vol. viii. p. 321.

accurately the total carbon contained in iron or steel by direct combustion, without previously separating the iron? (2.) Can this carbon be determined direct by oxidation in the wet way, the iron being also present? (3.) If the carbon has been separated by the action of neutral metallic salts, such as copper sulphate or cupric chloride, is it necessary to separate the carbon, before its oxidation, from the metal with which it is in admixture?

The author's numerous experiments lead him to answer these questions in the following manner:—(1.) Direct combustion in oxygen, whether the iron contains little or much carbon, gives inaccurate results. (2.) The total carbon can always be accurately determined, without any previous separation of the iron, by means of chromic and sulphuric acids, but if dilute sulphuric acid is used there is always the possibility present of the evolution of small quantities of hydrocarbons, except a large excess of chromic acid is present. It is, therefore, desirable to pass the gaseous products of the oxidation over red-hot cupric oxide in the usual manner. It is always better to have larger quantities of chromic acid in the solution than are usually employed. (3.) If the carbon is deposited by a solution of a copper salt, it is not necessary to separate the carbon from the copper before its oxidation in the wet way, as if the sulphuric acid is not very concentrated, in the presence of chromic acid in the solution, only traces of sulphurous acid can escape, and the error due to this source would be less than those due to frequent manipulation. If, on the other hand, the oxidation of the carbon is to be effected by combustion in the dry, then the copper must in the first instance be removed by solution.

The author is of opinion that in the case of an iron containing graphite, the best method for the determination of the total carbon consists in direct oxidation by means of a solution containing sulphuric and chromic acids, followed by a combustion tube with copper oxide, &c. The chromic acid must be present in at least twelve or fifteen times the quantity of the iron present. No direct combustion method in the dry gives good results, and neither does the Wöhler chlorine method, nor indeed any method in which the carbon is first separated by the action of a salt solution, followed by a combustion in the dry way.

If the iron contains no graphite, then the best is the Wöhler chromic method, followed by a combustion of the residue in a current of oxygen. If, however, much manganese is present, then the chromic-sulphuric acid method is the best; while, if the metal cannot be obtained in a finely divided form, then the Weyl method should be employed. In this the

solution of the metal is effected by means of an electric current. The residue should then be oxidised by the chromic-sulphuric acid method.

With reference to the determination of the graphitic carbon in iron and steel, the author points out that it is desirable to boil the metal for some time with hydrochloric or nitric acid, as this long boil not only gives better results than could otherwise be obtained, but renders the treatment of the residue with caustic potash, alcohol, and ether unnecessary. If nitric acid is employed, then under identical conditions the results are apt to be lower than if hydrochloric acid had been employed as the solvent, and yet the use of nitric acid is preferable to that of the hydrochloric acid, as it acts more quickly in leaving a residue of graphite free from the non-graphitic forms of carbon. The author makes various suggestions as to the apparatus that should be employed in the determinations of the total carbon.

W. Hempel* partially exhausts a flask containing 0.5 gramme of the iron to be examined, 2.3 grammes of metallic mercury, and a mixture of chromic and sulphuric acids with water. The gas evolved is measured, and the carbonic anhydride produced determined by absorption with caustic soda solution. The apparatus used is described and illustrated, and the results are stated to be very satisfactory.

R. Lorenz,† in reply to De Koninck, states that fusion with lead chromate in a current of oxygen at a white heat, causes the complete oxidation of the carbon, and doubts whether the same satisfactory result could be obtained by the use of borax or microcosmic salt, even when mixed with copper oxide.

C. B. Dudley and F. N. Pease‡ place 3 grammes of the finely divided steel in a half-litre beaker, and cover it with 200 cubic centimetres of heated acid solution of potassium-copper chloride. During the progress of the reaction the charge is agitated constantly. As soon as the precipitated copper has again passed into solution, the carbon is allowed to settle out, filtered through asbestos, washed with dilute hydrochloric acid, and finally with water, until the chlorine reaction ceases. The total filtrate is finally diluted to such an extent as to enable it to be readily ascertained whether any carbon has passed through the filter. If this has happened, the analysis is a failure; but if not, the asbestos, with the platinum boat in which it is contained, is first dried at a temperature which must not exceed 100° C., and is then transferred to the

* *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xli. p. 658.

† *Zeitschrift für Angewandte Chemie*, 1893, pp. 635-637.

‡ *Journal of the American Chemical Society*, vol. xv. pp. 450 and 501.

combustion tube. The combustion of the carbon is then effected in a manner which the authors describe and illustrate by the aid of sketches. Another sketch shows a stirring arrangement for 12 beakers. The best kind of asbestos to use as the filter is actinolite, cut into short pieces. The preparation of the filter is described, as well as that of the solution of copper-potassium chloride that is used. Various points in connection with this method are referred to, but it is shown that notwithstanding various possible sources of error, the carbon determinations are accurate to 0.005 per cent.

In a letter to the Committee on International Standards for the Analysis of Iron and Steel, T. M. Drown* reports some experiments on dissolving steel in copper salts. Copper chloride acidified with 20 per cent. of hydrochloric acid dissolves the iron with fair rapidity. When 40 per cent. of hydrochloric acid is used, loss is apt to occur. The addition of alkaline chloride, however, facilitates the solution. Good results were obtained by using for 3 grammes of steel a solution containing 12 grammes of copper as chloride, 15 cubic centimetres of hydrochloric acid of specific gravity 1.2, and 60 cubic centimetres of sodium chloride solution (320 grammes per litre).

F. J. R. Carulla† describes the different methods of determining carbon in steel, including Koppmayer's specific gravity tests, Ryder's magnetic tests, and Eggertz's colorimetric method. Reference is also made to the methods described by J. E. Stead‡ and by A. E. Hunt§. Other variations of Eggertz's test are also dealt with.

The Determination of Phosphorus.—J. Spüller and S. Kalman|| give the following method for the determination of phosphorus in pig iron or steel high in silicon. The silica resulting on the solution of the metal, they find, need not be filtered off provided no ammonia salt is present, and that the temperature does not exceed 40° C. About 3.3 grammes of steel is dissolved in a 250 cubic centimetre Erlenmeyer flask, in from 50 to 55 cubic centimetres of nitric acid of 1.2 specific gravity, heating to effect the solution, and then boiling to eliminate nitrous fumes. To this solution there is added 8 cubic centimetres of a 3 per cent. solution of potassium permanganate, and the whole boiled

* *School of Mines Quarterly*, vol. xv. p. 156.

† Paper read before the Derby Society of Engineers, November 3, 1893; *Industries and Iron*, vol. xv. pp. 710-711.

‡ *Journal of the Iron and Steel Institute*, 1883, No. I. p. 213.

§ *Ibid.*, 1883, No. II. p. 764.

|| *Zeitschrift für Analytische Chemie*, vol. xxxii. pp. 538-550.

until the red colour has disappeared. After the precipitated manganese oxide has been reduced by the addition of 4 cubic centimetres of a 10 per cent. solution of potassium nitrite, and the excess of nitrous acid eliminated by heating, the solution is allowed to cool to about 55° or 60° C., when 80 cubic centimetres of the ordinary ammonium molybdate solution is added, the solution shaken for a couple of minutes, and allowed to stand for two hours at a temperature of 36° or 40° C. The precipitate is filtered through a double filter, washed in the ordinary way, redissolved in dilute ammonia, the solution evaporated to dryness in a porcelain dish, and the residue weighed. One hundred parts of this residue contain from 1.64 to 1.65 part of phosphorus. The method is the same in the case of pig iron, except as regards the quantities of material, acids, &c., employed.

A. Villiers and F. Borg* are of the opinion that, if in the complete absence of alumina and iron, the phosphoric acid is precipitated by ammonium molybdate, the precipitate formed has the constant composition $P_2O_5 \cdot 24 MoO_3 \cdot 3(NH_4)_2O \cdot 3H_2O$. This precipitate contains 3.728 per cent. of phosphoric anhydride. Only ordinary precautions are necessary, and the temperature at which the precipitation is effected should not exceed 15° C. If iron or alumina is present, some of it will pass into the precipitate, and even if this precipitate is redissolved and reprecipitated with magnesia mixture, the precipitate so obtained will still be impure. Very accurate results are stated to be obtained if the molybdate precipitate is washed by decantation, the part that collects on the filter dissolved in ammonia, added to the main bulk of the precipitate, and when the solution is complete tartaric acid is also added. The solution may be acidulated in this way, without the phospho-molybdate being reprecipitated. The solution is then made slightly ammoniacal, and the phosphoric acid precipitated with magnesia mixture, in which case both iron and alumina remain in solution. The molybdate solution employed by the authors, is obtained by dissolving 150 grammes of ammonium molybdate in warm water, diluting with cold water to 1 litre, and pouring the solution into a similar bulk of nitric acid of 1.2 specific gravity.

The method for the determination of phosphorus by titration of the yellow precipitate, as described by H. Pemberton,† is favourably commented upon by W. J. Williams,‡ F. Bergami§ and Dr. B. Terne,|| all

* *Comptes Rendus de l'Académie des Sciences*, vol. cxvi. pp. 989-993.

† *Journal of the Franklin Institute*, vol. cxxvi. pp. 362-376.

‡ *Ibid.*, vol. cxxxvii. pp. 128-128.

§ *Ibid.*, pp. 129-133.

|| *Ibid.*, pp. 138-140.

of whom have experimented with this method on various phosphorus-containing compounds.

J. O. Handy* classifies the methods used for the determination of phosphorus, and gives a molybdate method for the exact determination of phosphorus in iron, steel, and ores when arsenic is present. Phosphorus is determined by the acetate methods which are long and difficult; by the molybdate methods in which the phospho-molybdate is weighed, or estimated volumetrically by permanganate or by alkali; and third by combination methods which use acetate or molybdate and magnesia. In the molybdate methods, arsenic is usually disregarded, but experiments show that arsenic is mechanically carried down with the precipitate if much phosphorus is present. When the percentage of phosphorus is small, arsenic does not interfere. The method of freeing the phospho-molybdate precipitate from arsenic is as follows:—After precipitation by any good method, it is washed with a 1 per cent. solution of nitric acid, and is then dissolved into a 12-ounce flask, by a one in six solution of ammonia. The solution is diluted from about 15 up to 75 cubic centimetres, and is heated to 75° C. Ten cubic centimetres of nitric acid and 25 of molybdate solution are added, the precipitate is washed with dilute nitric acid or nitric acid and potassium nitrate, and weighed or titrated.

J. O. Handy and G. O. Loeffler† find that the yellow precipitate may be weighed immediately after it is taken from the oven, or after cooling in a desiccator. After cooling in the air the results are too high. They have also determined that Wood's molybdate solution may be used four hours after manufacture, and that phosphorus cannot be completely precipitated at 25° C. by five minutes' shaking.

A. G. McKenna‡ finds that lower results are obtained by oxidising with permanganate than by evaporation to dryness, when the sample is chilled iron. This is probably due to incomplete oxidation of the phosphorus, as the colour due to carbon is not completely discharged. The two methods are given with some results.

Both F. C. Phillips§ and R. B. Carnahan|| find it convenient to use a stream of natural gas or air for agitating the solution in the precipitation of the phospho-molybdate.

* *Proceedings of the Engineers' Society of Western Pennsylvania*, vol. ix., No. 10, pp. 31–36.

† *Ibid.*, vol. ix., No. 6, pp. 50–51.

§ *Ibid.*, p. 53.

‡ *Ibid.*, pp. 51–53.

|| *Ibid.*, p. 54.

The Determination of Manganese.—E. H. Saniter* reviews some of the methods in general use for the estimation of manganese in minerals and metals. In England, the process most generally used is that of Pattinson, or the modification by Riley, in which calcium carbonate is replaced by zinc oxide. On the continent Volhard's volumetric process is extensively used, and in America, weighing the manganese as pyrophosphate is considered most accurate. The gravimetric method with Mn_3O_4 is used in all countries. The results obtained with these several methods are given, and are commented upon at some length, being summarised as follows:—The weighing of manganese as Mn_3O_4 is utterly unreliable if precipitated as MnO_2 , but is somewhat better if precipitated as MnS . The weighing as pyrophosphate is accurate if the solution is absolutely free from other metals, but the numerous operations necessary render this very tedious. The volumetric methods of Pattinson and Volhard have a tendency to give low results in the hands of many chemists, and, if used, should be carefully standardised on manganese oxide of known composition at frequent intervals. Thus standardised, they are more accurate and more rapid than the gravimetric methods.

According to A. Gorgeu,† when manganese is estimated, as in Guyard's method, by adding a solution of potassium permanganate to an almost neutral solution of manganous chloride, heated at 80° , the results are too low, partly in consequence of the acidity of the liquid. Donath's modification, in which the solution of the manganous salt is added to a solution of the permanganate mixed with sodium carbonate, also gives inexact results, unless the solutions are mixed very slowly, especially towards the end of the reaction. If Guyard's process is modified by adding precipitated calcium carbonate before the permanganate, the results are less exact than by Donath's method.

According to Guyard, three manganese permanganates, Mn_5O_{10} , Mn_6O_{11} , Mn_7O_{12} , can be obtained by mixing potassium permanganate and manganous chloride in different proportions. He seems, however, to have overlooked the fact that hydrogen chloride is liberated at the same time. The author finds that the oxide Mn_7O_{12} is never formed, even when the liquid is kept neutral, and the two oxides, Mn_6O_{11} and Mn_5O_{10} , are formed only when the acid that is set free is continually neutralised with calcium carbonate. The author criticises Guyard's

* *Journal of the Society of Chemical Industry*, vol. xiii. pp. 112–116. A copy of this paper has been presented by the author to the library of the Iron and Steel Institute.

† *Bulletin de la Société Chimique*, vol. ix. pp. 490–496.

views as to the constitution of these oxides, and contends that there is no evidence that they are manganese permanganates, and also that Guyard has advanced no evidence of existence of manganese manganates.

The Determination of Silicon.—L. L. de Koninck * dissolves the iron in nitric or nitro-hydrochloric acid, and, if it is free from manganese, precipitates it with ammonia or ammonium carbonate, while, if manganese be present, the acetate must be used instead, care being taken that any ammonia used is free from silica. The precipitate is collected on a filter, washed, and ignited. It is then placed in a platinum boat and heated in a current of hydrochloric gas. The silica and alumina remain in the boat, and these may be weighed, and the silica subsequently eliminated by hydrofluoric acid, the alumina being again ignited and re-weighed.

The Determination of Sulphur.—A. H. Hooper † dissolves 5 grammes of the metal in dilute hydrochloric acid, and passes the sulphuretted hydrogen evolved into a vessel containing about 10 cubic centimetres of caustic soda solution free from sulphur, and of the specific gravity 1.20. When the absorption is complete, the soda solution is diluted and then titrated with a standard solution of lead nitrate. This is dropped in slowly, shaking constantly, until a drop of the lead solution ceases to produce a brown coloration.

The Determination of Chromium.—J. Spüller and S. Kalman ‡ find that fusion with caustic soda and sodium peroxide is not well adapted for the decomposition of hardened chrome steel. It is, however, applicable to ferro-chrome and to chromite, as well as to ferro-silicon and ferro-tungsten.

The Determination of Tungsten.—P. Kemery, § for the determination of tungsten in steel, dissolves 3 to 5 grammes in nitric acid, evaporates to dryness, and heats for no longer than five minutes after the fumes cease. The residue is cooled, and the iron dissolved out with 20

* *Revue Universelle des Mines*, vol. xxiii. pp. 405-406.

† *Chemical News*, vol. lxviii. p. 191.

‡ *Chemiker Zeitung*, vol. xvii. p. 1412; compare *Journal of the Iron and Steel Institute*, 1893, No. II. p. 537.

§ *Proceedings of the Engineers' Society of Western Pennsylvania*, vol. ix., No. 5, p. 11.

cubic centimetres of hydrochloric acid and 50 of water. The residue is washed on a filter with 5 per cent. hydrochloric acid until free from iron. The yellow tungsten oxide is then dissolved off the filter by strong ammonia, the solution being run into a platinum dish, where it is evaporated to dryness on a water bath. After ignition it is weighed as WO_3 containing 79.31 per cent. of tungsten.

When silicon has also to be determined, 5 grammes are dissolved in nitric acid, 10 cubic centimetres of sulphuric acid are added, and the solution evaporated until copious fumes of sulphuric anhydride are evolved. Cool, take up with hydrochloric acid as above, and weigh the residue as silica and tungsten oxide. The residue is evaporated with sulphuric and hydrofluoric acids to remove the silica, leaving tungsten oxide as before.

J. O. Handy* adds an index to the recent literature on tungsten estimation.

The Determination of Nickel.—A. T. Eastwick† describes a rapid method for the determination of nickel in steel. It depends on the insolubility of sulphide of nickel and the solubility of sulphide of iron in a nearly saturated solution of ammonium sulphate which is slightly acidulated with free sulphuric acid. One gramme of the sample is dissolved in 50 cubic centimetres of 20 per cent. sulphuric acid, the solution is boiled down to 35 cubic centimetres, cooled, and rendered slightly ammoniacal with half and half ammonia. Five grammes of ammonium sulphate is added, and then sulphuretted hydrogen is passed through the boiling solution for twenty minutes. The beaker is then washed down, first with boiling water, and then with hot 5 per cent. sulphuric acid, using as little as possible. The solution is boiled for a few minutes until the precipitate is flocculent and settles quickly. If it does not do this a little more acid must be added. Filter on to a small filter, wash well with hot 5 per cent. ammonium sulphate solution, and finally once with hot water. Transfer the filter and precipitate to a beaker, add $\frac{1}{2}$ gramme of potassium chlorate, mix well, and add 10 to 15 cubic centimetres of strong hydrochloric acid. Cover quickly, and, after the violent action, add an equal amount of hot water, and heat till the sulphide is decomposed. Filter, and wash well with hot water, then precipitate the small amount of iron in the filtrate with excess of ammonia. The precipitate must be dissolved and reprecipitated. The

* *Proceedings of the Engineers' Society of Western Pennsylvania*, vol. ix., No. 5, p. 12.

† *Ibid.*, pp. 7-10.

solution containing the nickel is acidified with hydrochloric acid, and copper is separated by sulphuretted hydrogen. Nearly neutralise the solution, and precipitate the nickel by a very slight excess of ammonium sulphide. The precipitate is ignited and weighed as nickel oxide, NiO , or the nickel may be determined electrolytically. At no stage should the solution exceed 150 cubic centimetres in volume. The time required is three to four hours.

J. O. Handy * adds a bibliography of the recent literature on nickel estimation.

H. von Jüptner † discusses the separation of nickel and cobalt in the analysis of steel. The customary methods, he observes, are very tedious, so much so, indeed, that in works laboratories they are only unwillingly employed. Fresenius has shown that in the presence of cobalt and of nickel small quantities of iron may be separated completely if to the hot solution ammonium chloride is added, and then an excess of ammonia, and the precipitate allowed to remain for several hours in the hot. This is then redissolved and reprecipitated twice. The whole of the cobalt and nickel remains in the solution, and can be obtained by evaporating to dryness, heating to eliminate the ammonium chloride, adding ammonium sulphide, and subsequently neutralising with acetic acid. The author states that he has found that this process is accurate when the iron is even as much as two hundred times the weight of the nickel and cobalt present. If manganese has gone into solution, as well as the nickel and the cobalt, the ammonium sulphide precipitate must be treated with an excess of acetic acid. This dissolves the manganese sulphide, leaving the sulphides of nickel and cobalt undissolved. The further separation of these two metals can then be effected by one or other of the usual methods. If alumina is present as well as a ferric oxide, R. Fresenius replaces the ammonia by ammonium carbonate, but Tamm has shown that in this case the manganese carbonate precipitate carries some cobalt down with it. The author consequently employs the ammonia method, observing that any alumina that may be precipitated passes into solution on the treatment with acetic acid.

The author has endeavoured to employ this method for the separation of chromium from iron, but the results were unsatisfactory.

* *Proceedings of the Engineers' Society of Western Pennsylvania*, vol. ix., No. 5, pp. 11-12.

† *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xli. p. 616.

II.—ANALYSIS OF IRON ORES AND SLAG.

Titration of Iron.—Storch * recommends the use of metallic copper, previously washed with alcohol and ether, and then with water, for reducing iron for titration. On warming, the reduction occurs readily. At the end-reaction the colour changes from greenish-blue to violet.

According to R. W. Mahon,† when iron ores are treated by fusion with alkaline carbonates in a platinum crucible, and subsequent solution in hydrochloric acid, some platinum may be attacked by the flux, and thus brought into the solution. In that case, when the titration of the iron is reached, the tin chloride first reduces the iron, and afterwards the platinum tetra-chloride to platinum dichloride, giving first a colourless solution and then a coloured one. Some error is in this way introduced on titrating. If the amount of tin chloride added is so regulated that the addition is stopped when a colourless solution is first obtained, the difficulty may be avoided.

The Colorimetric Determination of Iron.—A. Zega ‡ describes a colorimetric method for the determination of iron in very dilute solutions. The iron must be present as a ferric salt. To 100 cubic centimetres of the solution 1 cubic centimetre of concentrated nitric acid is added. The solution is shaken, and there is then added 5 cubic centimetres of a 5 per cent. solution of ammonium sulphocyanide. Hydrochloric acid is not so good as nitric acid as an addition, the colour test being then much less delicate. One hundred cubic centimetres of distilled water is then treated in exactly a similar manner, a standard ferric solution being run in from a burette until the colour resulting is identical with that of the solution being examined. The test is remarkably delicate.

Microchemical Detection of Iron.—The method of detecting iron in microchemical examinations, recommended by J. Lemberg, § consists in the addition of ammonium sulphide to a granule of soluble substance on a microscope slide. A black coloration indicates the presence of FeS. A black sulphide is, however, not distinctive for iron. On re-

* *Berichte der Oesterr. Gesellschaft*, vol. xv. p. 9.

† *American Chemical Journal*, vol. xv. pp. 578-582; *School of Mines Quarterly*, vol. xv. p. 151.

‡ *Chemiker Zeitung*, vol. xvii. p. 1564.

§ *Zeitschrift der deutschen geologischen Gesellschaft*, vol. xlv. p. 823.

moving the excess of ammonium sulphide, and adding a drop of concentrated aqueous solution of potassium ferricyanide, the black sulphide of iron is converted to Turnbull blue in about eight minutes.

The Determination of Phosphoric Anhydride.—In the method of volumetrically determining phosphoric anhydride proposed by A. F. Holleman,* to 50 cubic centimetres of the solution, containing not more than 0.2 gramme of phosphoric anhydride, 10 cubic centimetres of normal sodium bicarbonate solution is added, which is followed by a slight excess of decinormal silver nitrate. The solution is then nearly neutralised with decinormal soda. After diluting and filtering off silver phosphate, the excess of silver remaining in solution is determined by Volhard's method.

H. Pemberton † claims priority in the method by acidimetric titration of the yellow precipitate.

H. von Jüptner ‡ has experimented with a view to ascertain whether the ordinary method for the determination of phosphoric acid in iron ores, where a large quantity of insoluble residue results, is or is not accurate, whether, that is, all the phosphoric acid passes into the solution, or whether a portion remains in the undissolved residue. To ascertain this, heavy-spar was mixed in with the ore, and it was found that the subsequent results obtained in the determination of the phosphoric acid were too low. The residue should, therefore, be fused with fusion-mixture, and the phosphoric acid it contains determined.

Adulteration of Basic Slag.—In discussing the value of basic slag as a fertiliser, E. Wrampelmeyer§ points out that natural phosphate is sometimes coloured so as to resemble basic slag, finely powdered coal being added for this purpose. The following methods for detecting adulteration are given:—(1.) Estimation of loss on ignition in a Kössler furnace. The loss in old samples of basic slag is slight, whilst with fresh samples there is a gain owing to oxidation. (2.) Estimation of substance soluble in warm water after ignition. (3.) Determination of specific gravity. Basic slag has a specific gravity of 1.9 or higher, whilst all the other phosphates examined varied from 1.1 to 1.6. (4.) Estimation of

* *Recueil des travaux Chimiques des Pays-Bas*, vol. xii. pp. 1-11.

† *Journal of the American Chemical Society*, vol. xv. p. 382; *School of Mines Quarterly*, vol. xv. p. 155.

‡ *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xli. p. 616.

§ *Landwirthschaftliche Versuchs-Stat.*, vol. xliii. pp. 183-190.

phosphoric acid soluble in citric acid (Loge's method), and in ammonium citrate (Petermann's method). Results of examination of various phosphates show that the microscopic examination and a determination of the specific gravity are generally sufficient for ascertaining whether the slag is genuine or not. In two cases, however, the microscopic examination and solubility in water, citric acid and ammonium citrate indicated genuine slag, whilst the low specific gravity and the high loss on ignition clearly pointed to adulteration. The suspected sample should always first be examined with a microscope, then, if necessary, the loss on ignition and the specific gravity, and the solubility in water should be determined. Lastly, if any doubt remains, the solubility should be determined by Loge's and Petermann's methods.

III.—GAS ANALYSIS.

The Determination of Nitrogen.—L. Lang* determines the nitrogen contained in coal gas in the following manner. About 20 cubic centimetres of the gas is measured off, placed in a Bunte burette, 125 cubic centimetres of air is added, and the mixture is ignited in a Hempel explosion pipette. The carbonic anhydride and oxygen are absorbed, and the volume of the residual nitrogen is measured. That of the nitrogen added being known, the difference represents the volume of the nitrogen contained in the gas under examination.

Analysis of Producer Gas.—F. Fischer† describes and illustrates an apparatus for the analysis of mixed producer gas. A certain quantity of the gas to be assayed is drawn into a measuring tube filled with mercury, then forced into a receptacle where it can be treated with caustic potash solution, or with pyrogallate, into which, after measurement of the gas absorbed, a definite quantity of air can be admitted. Then the residual hydrogen and hydrocarbons are burnt by the action of a platinum spiral heated to redness by a couple of batteries and the change of volume again noted, and the carbonic anhydride and oxygen absorbed. In a case the author quotes, these readings were as follows :—

* *Journal für Gasbeleuchtung*, vol. xxxvi. p. 493.

† *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xli. pp. 584–586, one illustration.

	Cubic Centimetres.
Quantity of gas used	50·2
After absorption of carbonic anhydride	42·6
After admission of air	99·2
After the combustion	80·8
After absorption of the carbonic anhydride	75·9
After absorption of the oxygen	72·2

The 56·6 cubic centimetres of air admitted contained 44·7 cubic centimetres of nitrogen, and the gas sample therefore $72·2 - 44·7 = 27·5$ cubic centimetres, and consequently $42·6 - 27·5 = 15·1$ cubic centimetres of combustible gas. As the combustion produced a diminution in volume of 18·4 cubic centimetres, and that of the carbonic anhydride was 4·9 cubic centimetres, it follows that the composition of the gas was as follows :—

	Cubic Centimetres.	Per Cent.
Carbonic anhydride	7·6	15·1
Carbonic oxide	4·4	8·8
Marsh gas	0·5	1·0
Hydrogen	10·2	20·3
Nitrogen	27·5	54·8
Totals	50·2	100·0

With but slight practice it is possible to obtain accuracy to within 0·2 per cent., and to complete the analysis within the period of half-an-hour. Of course, for more accurate determinations the usual precautions must be taken, such as those customary in reading off the volume, and in reducing to standard atmospheric pressure and temperature, but for works purposes the apparatus may be even further simplified.

IV.—FUEL ANALYSIS.

The Determination of Phosphorus in Coal and Coke.—In connection with the manufacture of special Bessemer pig iron, J. Lychenheimer* found it necessary to make a large number of determinations of the phosphorus in anthracite, which was found to vary considerably. To find the most rapid, and at the same time accurate, method, several experiments were made. It seemed certain that all the phosphorus was

* *Transactions of the American Institute of Mining Engineers*, Virginia Beach Meeting, 1894 (advance proof).

in the ash, so the ash from 5 grammes of the fuel was taken. In the first four methods this was fused and treated as directed by Blair or F. Crobaugh. It was ultimately found, however, that practically all the phosphorus was extracted from the ash by strong acid. For this purpose it is boiled with 40 cubic centimetres of strong hydrochloric acid, evaporated to one quarter, then 40 cubic centimetres of nitric acid of specific gravity 1.42 added, and evaporated until 20 or 25 cubic centimetres is left. The phosphorus in the solution is then determined. The results with the several methods are given, and the time for the last named method is an hour to an hour and a half. The fuel is burnt in a small tray about 2 inches square and $\frac{1}{2}$ inch deep, made from platinum foil. This is hung inside a short chimney, and heated by a bunsen burner.

STATISTICS.

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I.—UNITED KINGDOM.

Iron Trade Statistics.—The British Iron Trade Association has collected the following statistics * showing the production in 1893 :—

	Tons.
Pig iron, forge and foundry	3,349,694
Pig iron, hæmatite	3,130,620
Pig iron, spiegeleisen and ferro-manganese	169,686
Pig iron, basic	179,841
Pig iron, total	6,829,841
Puddled iron	1,363,974
Bessemer steel ingots, acid	1,230,992
Bessemer steel ingots, basic	262,362
Bessemer steel ingots, total	1,493,354
Finished Bessemer steel :—	
Rails	579,386
Plates and angles	45,932
Bars and forgings	296,843
Sleepers	31,716
Blooms and billets	206,994
Castings	3,749
Tires	14,418
Other descriptions	46,748
Total Bessemer steel	1,225,786

* *Iron and Coal Trades Review*, vol. xlviii. pp. 335, 399, 431.

	Tons.
Open-hearth steel ingots, acid	1,377,664
Open-hearth steel ingots, basic	78,645
Open-hearth steel ingots, total	1,456,309 *
Finished open-hearth steel :—	
Rails	39,304
Plates and angles	526,775
Bars	203,318
Blooms and billets	211,640
Castings	33,511
Forgings	27,532
Tires	61,051
Other descriptions	113,156
Total finished open-hearth steel	1,216,287

The number of furnaces in 1893 was as follows :—

Description.	No. at Work.	No. Erected.
Blast furnaces	310	695
Puddling furnaces	2,350	1,185
Bessemer converters, acid	47	83
Bessemer converters, basic	14	22
Open-hearth furnaces, acid	198	325
Open-hearth furnaces, basic	26	40

Imports and Exports.—According to the Board of Trade returns,† the exports from the United Kingdom during 1893 and 1892 were as follows :—

Description.	1893.	1892.
	Tons.	Tons.
Pig iron	839,869	767,053
Hoops, sheets and plates	139,603	140,117
Bar, angle, bolt and rod	148,931	173,414
Railroad	558,826	468,003
Wire	37,137	47,350
Tinplates	379,233	395,449
Cast and wrought	280,578	319,909
Old iron	118,551	106,488
Unwrought steel	169,764	149,131
Steel and iron manufactures	18,528	15,246

The imports into the United Kingdom during the same years were as follows :—

* The total is stated in the original to be 1,456,323.

† *Iron Trade Circular (Rylands)*, 1894, p. 56.

Description.	1893.	1892.
	Tons.	Tons.
Iron ore	4,065,863	3,778,653
Bar, angle, bolt and rod	65,820	75,915
Unwrought steel	8,935	7,083
Girders, beams and pillars	72,316	74,586
Unenumerated	150,702	143,773
Total iron and steel	297,773	301,357

II.—AUSTRALASIA.

Mineral Statistics of Victoria.—According to the official returns,* the quantity of coal raised in 1892 amounted to 23,363 tons, and that of lignite to 6600 tons.

Mineral Statistics of New Zealand.—According to the official returns,† the quantity of coal mined in New Zealand in 1892 amounted to 673,315 tons. The quantity imported from the Australian colonies was 125,453 tons, and the quantity exported was 84,414 tons.

The output of the different classes of coal was as follows:—

	Tons.
Bituminous coal	406,828
Pitch coal	89,549
Brown coal	149,460
Lignite	27,478

The number of men employed in connection with coal mining was 1681.

Small quantities of manganese ore are exported to Europe every year, but this is an industry that has not progressed.

III.—AUSTRIA-HUNGARY.

The Mining Industry of Austria.—According to the official statistics for the year 1892 ‡ of the land grants for mining purposes, 2292, or 6·02 per cent., related to the mining of iron ores; while 28,757, or 75·53 per cent., were coal lands. The iron ore lands had increased during the year by one, and the coal lands by as many as 1047.

* "Annual Report of the Secretary of Mines." Melbourne, 1893, p. 69.

† "The Mines Statement." By the Hon. R. J. Seddon, Minister of Mines. Wellington, 1893.

‡ *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlii. pp. 33-35, 40-44.

In Bohemia, at Steinhrovec, in the Schlan district, a rope boring was put down to a depth of 1118 feet. In the Brüz district a double shaft, over a thousand feet in depth, struck a seam of lignite, and another deep shaft was started to strike the main seam of this district, as the result of borings made in the previous year. In Lower Austria a shaft was put down to cut a 10-yard seam of lignite, and various discoveries of graphite, coal, and lignite were made in Moravia, Styria, Carniola, Dalmatia, Istria, and Galicia. A number of borings, exceeding occasionally a depth of 1000 feet, were made in Styria, but mostly without success. A good deal of the iron ore was mined open-cast.

Of mine railways there were in use altogether 1553 miles below ground, and 523 miles of surface lines; by far the greater part of this was in connection with the coal and lignite mines. Details are given of the methods of haulage in use, and of the machinery employed for pumping purposes. Other details refer to the various appliances in use for the dressing and concentration of fuel and ores. Full details are also published as to the number of the various kinds of furnaces and other appliances in use at the various metallurgical works.

At the Johannes Colliery of the Miröschauer Company, Bohemia, Brandt hydraulic drills were introduced during the year, and gave most favourable results, and a number of other improvements were introduced at other mines mentioned.

Imports and Exports.—Mr. Caspaar* gives in tabular form a series of statistics showing the imports and exports of Austria-Hungary for the year 1893, the similar figures for the previous year being also given. They contain the following:—

	Imports.		Exports.	
	1893.	1892.	1893.	1892.
	Metric Tons.	Metric Tons.	Metric Tons.	Metric Tons.
Lignite	20,111	18,338	6,763,186	6,748,844
Coal	3,840,874	3,352,129	648,424	653,667
Coke	309,861	254,000	108,576	87,745
Iron ore	73,248	71,679	106,259	108,120
Manganese ore	354	519	3,697	3,768
Total iron and iron wares	121,626	100,339	45,665	40,996
Forge pig iron	6,266	4,735	7,532	6,889
Foundry pig iron	53,457	41,108	1,692	1,043
Spiegeleisen	697	919	371	1,155
Ferro-alloys	1,808	681	871	885

* *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlii. pp. 147-150, 159-162.

Details are given for other kinds of iron and steel and their manufactures. Under the respective headings, lignite, coal, and coke, are included the briquettes made from those fuels.

The quantity of fire-bricks imported in 1893 was 2760 tons, whilst the exports were 3592 tons, the imports and exports of other shapes being respectively 2667 and 1731 tons.

Comparing the external trade of Austria-Hungary for the years 1893 and 1892, it will be seen that there has been a steady increase in the exports of lignite. In coal, too, the exports have largely increased, mainly to Germany, while the imports of coke have risen by 55,861 tons, and the exports of coke have also risen to the extent of 28,788 tons, most of which went to Russia.

Fifty-three per cent. of the total imports of iron ore in 1893 was from Sweden. Slight diminutions are shown in the exports of iron ores, the imports showing an increase of 1569 tons, while those of manganese ores show a very slight diminution.

The imports of iron and ironware have increased by 21,287 tons, and the exports by 4669 tons. Some 50 per cent. of the imports were from Germany, and 42 per cent. from the United Kingdom. Of the imports from the latter, 87 per cent. was pig iron.

The Iron Industry of Hungary.—F. Bleichsteiner,* observes that the consumption of iron and steel in Austria-Hungary is seven times as great now as it was fifty years ago, Hungary producing about a third the quantity which Austria produces. Before rolling was introduced, forges existed all over Hungary. The progress of the iron trade has been considerable, but in Transylvania, where the purest and richest deposits of ore occur, no important refinery has been started within the last ten years. The oldest ironworks in Hungary is that of Rhonicz, near Neusohl. In former years the position of this works was one of very considerable importance. It was surrounded by thickly wooded country, and water power was also abundant. The oldest known record of these works dates from June 30, 1580, but they are believed to have been long in existence at that period. The first puddling furnace was erected at Alt-Quatimech in 1839, and a rolling mill at Záhrenbach in the following year, and rails were rolled at Brezova in 1851. The only other rail mills existing in Austria at that time were those at Witkowitz and Prävali. Some details are given by the author as to the output of

* *Berg- und Hüttenmännisches Jahrbuch der k. k. Bergakademien*, vol. xli. pp. 203-234.

Hungary and of Austria, both as regards iron, iron ore, and coal, as well as other minerals, and he then proceeds to consider the deposits of each of these *seriatim*.

The deposits of coal are similar to those of the Alpine region generally, being almost entirely caking coals of recent formation. Coal of greater age occurs only in the Banat, at Szekul near Reschitza, and in the Eiben Valley in Szörényer county, but the deposit seems to be of small extent. The coal seams of the Lias, in the Steierdorf-Anina coal-basin, and especially the Fünfkirchen Liassic coals in the Baranya and Tolna counties, are of considerable size, and give for many purposes a useful coke, but for the iron industry they appear as yet to have assumed very slight importance.

In the valley of the Zsilt, lignite deposits occur. These belong to the Oligocene, and are the most important deposits of mineral fuel in Hungary. These seams can be traced for a distance of nineteen miles, and are occasionally over three miles wide. Twenty seams are known. Of these, eight are workable; some of them are as much as a hundred feet in thickness. It is hoped to be able to convert this material into a useful coke.

In recent coals Hungary is very rich, the Salgó-Tarján lignite seams having the greatest area among these. Other deposits of lignite are also mentioned, and a list is given of the outputs of the various mines, together with the value of the product and the number of the work-people employed.

According to W. Zsigmondy, the geological structure of the mountain districts of Hungary resembles generally that of the Alps. Granite and crystalline slates appear in places, whilst at others Mesozoic rocks occur, with Tertiary rocks adjacent. Palæozoic rocks are only of rare occurrence in Hungary, but the Mesozoic strata are largely developed, often surrounding mountains of granite and crystalline slate, and often themselves forming chains of considerable elevation. The author, however, is not quite in accord with these views. He points out that in Hungary the ore deposits occur under very different conditions to those in the Alpine districts. In Hungary the ore deposits are confined to the mountain ranges. The author considers the iron ore deposits of Hungary to have as their most important centre, the Gyala iron ore mines. This ore is rich in manganese, but free from phosphorus and sulphur. The deposit is worked open-cast, and the ore, which contains 50 per cent. of iron, is occasionally 330 feet in thickness. Similar parallel deposits exist, but they occur in the higher mountain ranges, and no means of communication exist at

present. Numerous other deposits of iron ore are also mentioned, some of which are being worked on a considerable scale. Brown iron ore and spathic ore appear to be the most common of the iron ores, and they are frequently rich in manganese. A list of active mines, with their outputs, is given.

The blast-furnace industry is passed in historical review, and it is shown that the sixty-four active blast-furnaces existing in Hungary in 1891 produced 318,250 metric tons of pig iron. Nine other blast-furnaces were not in blast. Some important wire ropeways are attached to the smelting works, bringing ore and charcoal from distances of many miles. Some iron foundries are mentioned, and the various existing rolling mills are briefly described.

The manufacture of Bessemer steel was begun in Hungary, at Reschitza, in the Banat, in 1867. Here there are now 4 Bessemer converters, 4 small open-hearths, 2 new open-hearths in the rolling mill, 1 3-high rolling mill for rails, 1 for girders, and 1 for sheets, in addition to puddling furnaces and a bar iron mill. The Bessemer process, on a small scale, has been successfully employed at Alt-Sohl and elsewhere. A list is given of the various rolling mills now existing in Hungary. The Hungarian ironmasters recognise the impossibility of competing for an export trade, and the necessity of finding a market for their wares at home.

Coal Mining in Hungary.—Among the more important of the collieries in Hungary, in the year 1893, were those of the Salgó-Tarján Company. These produced 900,000 tons of coal in the year, an increase of 18 per cent. as compared with the output in the previous year. The next largest undertaking of this kind was that of the Northern Hungary Colliery Company, which raised and sold 370,000 tons. The Gran collieries of the Budapest Company raised 140,000 tons, and collieries near Hunyad, in Transylvania, which had only been at work for the past two years, raised 13,000 tons a month, an output which is expected to be increased to 18,000 tons a month in the present year.*

The Ostrau Karwin Coal District.—The output of coal from this field amounted in 1892 to 4,583,535 tons. The quantity of coke also produced was 471,517 tons, and of briquettes 16,216 tons. The work-people employed numbered about 26,500. The coal surface area of the various collieries was about 20,500,000 acres. The winding shafts

* *Pester Lloyd*, January 3, 1894.

numbered 39, with a total depth of about 7·1 miles. The deepest shaft was down 1825 feet. Particulars are given as to the machinery in use, the lines of rails laid down, washing plants erected, fans employed, pumps, and other details. The explosives used during the year included 18 tons of powder, 223 tons of dynamite, 31 tons of meganite, and 23 of fire-damp dynamite. Details are given showing the quantity of coal raised, and of coke and of briquettes produced at ten collieries in this field, with the number of winding shafts, and of the workpeople employed.*

Coal in Servia.—For the purpose of comparison with the mineral statistics of Austria, it may be noted that, according to a recent consular report, there are at the present time in Servia six groups of mines under State management. These include the coal mines at Senié, Alexar, and Misach. Exploratory work is being done at the latter two, but the first named produced 58,769 tons in 1891, out of the total output of 100,263 tons. Other mines are being worked by private companies, the best known being that of Vrska Chuka, which extracted 20,434 tons of coal, and made 20,293 tons of briquettes. Lignite and oil shale are also worked. The total area in 1891 of coalfields under private companies was 9640 acres, 876 workpeople being employed.

IV.—BELGIUM.

Mineral Statistics.—Statistics have been published † of the production of coal and iron in Belgium in 1893. According to these statistics, the number of coal mines at work in 1893 was 123, with a total production of 19,407,254 tons, and stocks at the end of the year of 473,681 tons. The corresponding figures for 1892 were 124 mines, with a production of 19,583,173 tons, and stocks of 835,645 tons.

The blast-furnaces in operation in 1893 produced 89,420 tons of foundry pig iron, 429,319 tons of forge pig iron, and 241,557 tons of basic pig iron, giving a total production of 760,296 tons, compared with 753,268 tons in 1892.

The total production of the ironworks in 1893 amounted to 502,178 tons (126,493 tons of rails and plates, and 375,685 tons of miscellaneous iron). In 1892 the total production was 479,008 tons (117,027 of rails and plates, and 361,981 tons of miscellaneous iron).

* *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xli. p. 622.

† *Moniteur belge*, February 12, 1894; *Comité des Forges. Bulletin* No. 828.

The quantity of cast products, bars, &c., produced by steelworks in Belgium in 1893 was 273,058 tons, and of forged products, rails, plates, &c., 218,244 tons. The corresponding figures for 1892 were 260,037 tons and 208,281 tons.

Imports and Exports.—The following table* shows the Belgian iron trade imports and exports during the years 1893 and 1892:—

Description.	Imports.		Exports.	
	1893.	1892.	1893.	1892.
	Tons.	Tons.	Tons.	Tons.
Iron ore	1,683,464	1,679,443	171,110	225,650
Steel ingots	19,800	8,816	1,364	914
Steel beams	466	...	8,937	...
Steel rails	500	625	50,128	73,062
Steel, rolled	8,411	7,730	16,576	13,515
Steel, wrought	1,730	1,476	22,670	11,376
Pig iron	156,187	149,563	18,519	18,253
Scrap iron	27,291	24,614	9,709	9,494
Iron wire	5,525	4,729	883	2,270
Iron beams	636	...	64,504	...
Rails	373	56	18,826	15,600
Plates	2,079	1,297	63,000	54,344
Rolled iron	12,388	12,580	135,489	204,268
Nails	761	689	7,113	7,005
Finished iron	3,720	3,656	18,927	31,446
Castings	3,068	1,315	19,032	23,067
Rolling stock	921	1,426	33,428	39,442
Machinery	17,673	14,801	31,383	37,015

V.—CANADA.

Mineral Production.—E. D. Ingall† has published the following statistics of the mineral production of Canada in 1893:—

Description.	Quantity.	Value.
	Tons.	Dollars.
Iron ore	124,702	298,018
Coal	3,719,170	8,422,259
Coke	161,790	61,078
Fireclay	540	700
Manganese ore	228	14,458
Moulding sand . . . . .	...	1,000
Natural gas . . . . .	...	366,233
Petroleum, barrels	798,406	834,334
Nickel, lbs.	3,992,982	2,076,351

* *Moniteur des intérêts matériels*, vol. xliv. p. 209.

† *Engineering and Mining Journal*, vol. lvii. p. 419.

In reports covering 201 and 199 pages respectively, E. D. Ingall and H. P. H. Brumell * give full statistics of Canadian mineral production for 1890 and 1891.

The Iron Industry.—G. E. Drummond † discusses the condition of the iron industry in Great Britain and in the United States, and points out the natural fitness of Canada for the successful establishment of an iron industry. He enumerates the iron ore and coal deposits of Cape Breton, Nova Scotia, New Brunswick, Quebec, Ontario, Manitoba, and British Columbia, and shows that, although up to the present comparatively little has been accomplished in the actual work of proving and developing the mines, the careful preliminary explorations made render it evident that Canada is fully endowed with raw materials.

The history of the Canadian iron industry is traced from the establishment of the St. Maurice Forges in 1737. Since 1887 the pig iron industry has continued to make creditable progress. In 1891 the production of pig iron in Canada was 23,891 tons, whilst in 1892 the total rose to 51,000 tons. Full details are given of the plant in operation at the Londonderry Iron Company's works (two blast-furnaces), at the Nova Scotia Steel Company's works (two open-hearth furnaces), at the Pictou Charcoal Iron Company's works (one 55-foot blast-furnace), at John McDougall & Company's works (two blast-furnaces), and at the Canada Iron Furnace Company's works (one 40-foot blast-furnace).

With such a nucleus as the existing establishments afford, with ample supplies of raw material, and with a good home market, the Canadian iron industry cannot fail to rapidly expand.

Coal in Nova Scotia.—A report recently issued by the Department of Mines, Nova Scotia, states that the coal produce for the first nine months of last year was 1,682,713 tons, which is 235,000 tons more than in the same period of the preceding year. The coal was mainly sold in Canada, but some 16,000 tons were sent to the United States. It is of interest to note that Nova Scotia is steadily increasing its coal output. Up to 1852 its coal sales had only in one year reached 200,000 tons; in 1860 they passed 300,000 tons; in 1870, 500,000 tons; and in 1881 they were over 1,000,000 tons. Now they are at the rate of 172,000 tons monthly. In all some 5800 persons are employed at the mines; and each coal-cutter dealt with 562 tons in the nine months.

* *Annual Report of the Geological Survey of Canada*, vol. v. Reports S and SS.

† Paper read before the General Mining Association of Quebec, January 11, 1894.

VI.—FRANCE.

Mineral Statistics.—The final official French mineral statistics* for the year 1892 have been issued. The production of mineral fuel is stated to have amounted to 26,179,000 tons. Out of the 294 collieries in France which were in operation, 136 have worked at a loss. The year was a very favourable one as regards accidents, of which there is none to record. Fire-damp did not cause a single death, a fact which is without precedent during a space of fifty years.

The production of pig iron during 1892 was 2,057,000 tons, that of wrought iron 829,000 tons, and that of steel 682,000 tons.

The total production of coal † in the various departments of France in 1893 was 25,738,073 tons, as against 26,178,701 tons in 1892, or a diminution of 440,428 tons. In the department of the Nord the increase is 248,508 tons, and in the department of the Pas-de-Calais there is a decrease of 841,952 tons.

Of forge pig iron and foundry pig iron 2,032,567 tons was produced in 1893, as compared with 2,057,258 tons in 1892. The quantity of forge pig iron produced in 1893 was 1,551,131 tons, and of foundry pig iron 481,436 tons.

The quantity of manufactured iron produced in 1893 was 829,851 tons, as compared with 828,519 tons in 1892. Of finished steel, the total quantity produced was 668,665 tons, and of steel ingots 803,063 tons. The corresponding figures for 1892 were 682,527 tons and 825,486 tons respectively. The worked steel in 1893 consisted of 218,021 tons of rails, 328,991 tons of merchant steel, and 121,653 tons of plates.

Consumption of Rails.—The quantities of steel rails received ‡ into the works on account of the principal French railway companies during the year 1893 were as follows:—Northern Railway Company, 18,757 tons; Western, 11,551 tons; Eastern, 28,371 tons; Paris-Lyons-Mediterranean, 35,439 tons; Orleans, 21,640 tons; Midi, 9660 tons; State, 3920 tons. Total, 129,338 tons.

The summary statement given below of the total quantities of rails received annually in the works by the French railways may be considered as approximately representing the consumption of rails in France during

* "Statistique de l'Industrie minérale et des appareils à vapeur en France et en Algérie."

† *Comité des Forges, Bulletin*. No. 820.

‡ *Ibid.*, No. 807.

the following years :—1869, 183,628 tons ; 1875, 217,546 tons ; 1880, 208,553 tons ; 1883, 341,334 tons ; 1884, 284,031 tons ; 1885, 249,416 tons ; 1886, 170,595 tons ; 1887, 108,898 tons ; 1888, 93,868 tons ; 1889, 58,046 tons ; 1890, 66,844 tons ; 1891, 112,857 tons ; 1892, 163,840 tons ; and 1893, 129,338 tons.

Imports and Exports.—The following table* shows the French iron trade imports and exports (in metric tons) during 1893 and 1892 :—

Description.	Imports.		Exports.	
	1893.	1892.	1893.	1892.
	Tons.	Tons.	Tons.	Tons.
Coke	1,443,421	1,423,619	56,806	56,033
Iron ore	1,630,442	1,683,723	302,673	304,646
Pig iron	85,949	86,996	104,689	120,755
Wrought iron and steel .	21,587	18,424	30,467	30,302

Mining in the French Colonies.—According to the reports published by the French Ministry of Public Works, the most important nickel ore district in New Caledonia is that of Thio. The 22 mines of this district afford occupation to 1158 miners, and produce 19,741 tons of nickel ore, containing 7 to 10 per cent. of nickel.

The number of chrome ore mines amount to 15, the most important being those of the N'Go and Pirogen rivers, which are connected by 3 miles of railway with the coast. From the seven workings in this district, which employ 150 miners, 2254 tons was exported in 1889, the yield being 50 per cent. of chromic oxide.

In Tonking numerous mining properties are undergoing development. The daily production of the Hon-Gay Colliery amounts to 25 tons. The length of galleries in use is 1500 yards, and 1500 to 1600 natives and 38 Europeans are employed.

Mineral Resources of Algeria.—The minerals chiefly found in Algeria† are magnetic oxides, red and brown hæmatites, carbonates, copper and iron pyrites often containing lead and silver, argentiferous lead, antimony, mercury, and finally, zinc in large quantity and of good quality. The number of known metalliferous deposits is estimated at 200.

* *Comité des Forges, Bulletin* No. 805.

† *Bulletin du Musée Commercial*, March 17, 1894.

Of this number there are at present 51 conceded deposits, 25 of which are in the department of Constantine, 16 in that of Algiers, and 6 in that of Oran. The most important enterprise is Aïn-Mokra, near Bône, belonging to the Mokta-el-Hadid Company. The ore worked is magnetite, containing 62 per cent. of iron. The mines give employment to 800 workmen, and to 8 steam-engines of 190 horse-power, and produce 130,000 tons, of a value of £45,200. The output is carried from the mine to the port of Bône by a railway 23 miles long.

The same company works the mine of Beni-Saf, of equal importance, at the other extremity of Algeria, and for which it has constructed the port of Beni-Saf. The iron mines of Tilfila, near Philippeville, yield an ore which gives 70 per cent. of iron.

Early French Metallurgy.—P. Mahler and B. H. Thwaite* describe the early metallurgical methods in vogue in France. The illustrations accompanying the paper are mostly reproduced from the "Description des Arts et Metiers," published in 1761, and comprise (1) the shield of a metallurgical guild; (2) a Catalan forge; (3 and 4) a French blast-furnace of the eighteenth century; (5) an old French iron foundry; (6) a cast iron medallion of Louis XV.; (7) a refining forge; (8) an early French rolling mill; and (9) forging an anchor.

VII.—GERMANY.

Iron Trade Statistics.—H. Rentzsch† has compiled from the German official statistics a comparative statement showing the position of the iron and steel industry in Germany and Luxemburg in the years mentioned. With reference to iron ore the details are as follows:—

	1890.	1891.	1892.
Mines in operation	755	681	610
Production of iron ore, tons	11,406,132	10,657,522	11,539,133
Value of ore per ton, shillings	4.19	3.70	3.58
Workpeople employed	38,837	35,390	36,032

* *Cassier's Magazine*, vol. v. pp. 305-313.

† *Verein Deutscher Eisen- und Stahl-Industrieller*, 1893, No. 17.

A second table refers to the production of pig iron :—

	1890.	1891.	1892.
Works in operation	108	109	109
Pig iron produced, tons	4,658,451	4,641,217	4,937,461
Value per ton, shillings	57'44	50'08	46'44
Workpeople employed	24,846	24,773	24,325
Ores smelted, tons	11,908,846	11,800,129	12,604,939
Existing blast-furnaces	268	270	266
Active blast-furnaces	222	218	215
Weeks in blast	10,480	10,322	10,103

Details are given showing the outturn of the various kinds of pig iron. Foundry and acid and basic Bessemer pig iron show largely increased outputs during the period under review, while the forge pig iron production has considerably diminished.

There were 1193 iron foundries in 1892, employing 61,293 workpeople, melting 1,172,490 tons of pig iron and scrap, and producing 1,011,380 tons of castings. The respective figures for the year 1890 were as follows: 1148, 63,960, 1,181,278, and 1,027,384. The value of these products in 1892 was about £8,300,000, as compared with £9,330,000 in 1890.

The works making malleable iron in 1892 numbered 246, employing 45,989 workmen, and they produced 1,279,287 tons of manufactures and 84,006 tons of semi-manufactures. The figures for 1890 were: 255, 53,970, 1,486,658, and 72,405.

The works making ingot iron numbered, in 1892, 122. They gave employment to 61,092 workpeople, and produced 1,976,735 tons of manufactured products, and 779,482 tons of semi-manufactured. In 1890 these numbers were: 115, 52,823, 1,613,783, and 618,316.

The total tons of iron and steel manufactures are as follows :—

1890.	1891.	1892.
4,851,359	5,111,964	5,165,039

The author gives a correction for the 1892 production, which increases it to 5,176,615 tons.

The fuel produced in these years was as follows :—

	1890.	1891.	1892.
	Tons.	Tons.	Tons.
Coal	70,237,808	73,715,653	71,372,193
Brown coal	19,053,026	20,536,625	21,171,837

The number of workpeople employed in the coal mines was respectively 262,475, 283,227, and 289,415. Although the quantity of coal raised had increased in the period under review, its value had diminished by about £550,000. The workpeople employed in mining brown coal increased from 33,161 in 1890 to 37,480 in 1892, whilst those mining iron ore diminished in number from 38,837 to 36,032. The total number of workpeople employed in the iron ore mines and ironworks was 234,436 in 1890, 230,431 in 1891, and 228,731 in 1892.

During the period 1883–92, the output of iron ore in Germany and Luxemburg has increased from 8,756,617 tons in 1883 to 11,539,133 tons in 1892.* During this same period the production of pig iron has risen from 3,469,719 tons to 4,937,461 tons, the increase having been fairly regular in both instances throughout the several years of this period, except that in 1886 there was a diminished output in both iron ores and pig iron. The manufactured products of iron and steel have also steadily increased in quantity, the production having been 3,323,103 tons in 1883, while in 1892 it had risen to 5,165,039 tons. The value, however, has been much more fluctuating, for while in 1883 it was £26,317,072, the 4,851,358 tons produced in 1890 were valued at £37,185,000, while the larger output in 1892 was only worth £33,770,882. This does not appear to have been due to a diminished outturn of any one class of metal, but rather to a general diminution in the selling price. The outturn of malleable iron slightly diminished during the period under review, while that of ingot iron was nearly trebled.

Production of Pig Iron.—The total production of pig iron in Germany, including Luxemburg, was as follows in the years mentioned, the outturn for 1893 being that obtained from the returns collected by the Association of German Iron and Steel Workers, those for 1892 being the official figures :—

Description.	1892.	1893.
	Metric Tons.	Metric Tons.
Forge pig iron	1,491,596	1,564,285
Acid Bessemer pig iron	2,689,910	361,240
Basic Bessemer pig iron		2,271,293
Foundry pig iron	746,207	766,330
Scrap	9,748	...
Totals	4,937,461	4,963,148

* *Stahl und Eisen*, vol. xiii. p. 1100.

The figures shown for foundry pig iron for 1893 are probably too low, and the statistics for this year include neither charcoal pig iron nor scrap.

Of the various districts of Germany, the north-eastern group of blast-furnaces made, in 1893, 42·0 per cent. of the total quantity of basic Bessemer pig iron made, and still higher percentages in the case of the other kinds of pig iron, reaching as much as 83·0 in the case of the acid Bessemer metal.*

Iron Trade Imports.—The iron trade imports into Germany have been as follows in the years mentioned : †—

Description.	1892.	1893.
	Metric Tons.	Metric Tons.
Iron ore	1,655,843	1,573,202
Basic Bessemer slag	69,924	78,458
Scrap	6,419	8,178
Pig iron	209,306	218,998
Total iron and iron manufactures	278,457	286,631
Machinery, &c.	41,065	42,312

The Prussian Mining Industry.—The Prussian Ministry of Trade and Commerce has published the following table showing the power used in the mines of that kingdom in the year 1891 : ‡—

Mines.	Engines.							
	Horses.	Water.		Steam.		Electric.		Total.
	No.	No.	H.-P.	No.	H.-P.	No.	H.-P.	No. H.-P.
Coal	8,568	43	1,770	5,091	383,842	2	24	5,136 385,636
Lignite	425	9	135	1,768	37,852	...	...	1,777 37,987
Iron ore	93	10	95	395	11,610	...	...	405 11,705
Other metallic ores	600	201	2,930	802	33,869	...	...	1,003 36,799
Other minerals	83	...	...	206	10,779	...	...	206 10,779
Totals	9,769	263	4,930	8,262	477,952	2	24	8,527 482,906

No engines driven by compressed air would appear from the table to have been in use.

* *Stahl und Eisen*, vol. xiv. pp. 187-188.

† *Ibid.*, p. 276.

‡ *Ibid.*, vol. xiii. p. 1089.

VIII.—JAPAN.

Production of Coal.—For a few years past, Japan, with an annual production of 3,500,000 tons, has had more coal than is needed for home consumption. The exports now amount to fully 1,250,000 tons a year. Several cargoes have been sent to Bombay, and have there found a market.*

The duration of Japanese coal has recently been estimated as under twenty-six years. The annual increase in consumption is taken at 13 per cent., and the present known amount of coal is estimated at 759,720,000 tons.†

IX.—NATAL.

Production of Coal.—The report of the Commissioners of Mines of this colony for the year ending June 30, 1893, says that a number of diamond drill borings made at the cost of the government have shown the existence of valuable coal seams, but no new workings have been undertaken. The output of coal for the year was 129,255 tons, a slight increase over the preceding year. Of this output 105,068 tons was from the Dundee Colliery, and 12,797 tons from the Newcastle Colliery, the remainder coming from eight small workings. The average number of employes was 834, of whom 40 were white men, 690 natives, and 104 East Indians. Three men were killed and five injured by accidents.

X.—RUSSIA.

Mineral Statistics.—According to official statistics,‡ the iron trade production of Russia was as follows in 1892 and 1891:—

Description.	1892.	1891.
	Tons.	Tons.
Pig iron	919,614	861,420
Malleable iron	447,474	432,649
Manufactured iron —		
Castings	77,025	80,050
Telegraph wire	22,266	22,749
Enamelled ware	4,524	4,727
Forged iron and steel	103,611	111,983
Steel	305,003	260,430
Bituminous coal	5,425,527	5,275,462
Anthracite	664,342	596,870
Lignite	135,544	145,525
Coke	349,160	295,572
Petroleum	4,750,609	3,991,539

* *Board of Trade Journal*, vol. xvi. p. 217.

† *Industries and Iron*, vol. xv. p. 851.

‡ *Moniteur des Intérêts Matériels*, vol. xlv. p. 148.

Production of Coal.—The Russian official statistical returns* state that the output of coal in Russia in 1892 amounted to 422,010,500 poods, or 42,210,336 poods in excess of the quantity raised in the previous year. Of the total quantity of coal raised, 377,993,409 poods consisted of bituminous coal; 38,604,469 of anthracite; and 5,412,622 poods of lignite, &c. The output of the various coalfields was as follows:—

Coalfield.	1892.	+ or - as Compared with 1891.
	Poods.	Poods.
Donetz	217,532,677	+ 26,503,751
Dombrowa	175,993,231	+ 17,162,401
Ural	14,275,797	- 1,110,162
Moscow	10,971,815	- 49,475
Kusnetz	1,193,077	- 44,553
Caucasus	1,036,793	+ 547,183
Coast Region	776,460	- 301,865
Kieff	124,000	- 553,400
Kirghiz Steppes	106,450	- 32,550
Olonetz	200	- 100

Russian Iron Trade.—R. Helmhacker† traces the development of the Russian iron trade. The amount of iron ore smelted increases rapidly year by year. Expressed in thousands of poods, the quantities of iron ores smelted in 1882 and in 1890 were as follows:—

Description.	1882.	1890.
	Poods.	Poods.
Magnetite	11,095	17,703
Limonite	35,044	46,348
Hæmatite	14,186	21,836
Siderite		14,013
Bog iron ore	726	3,431
Slag		7,546
Totals	61,051	110,877

As fuel, charcoal is still chiefly used. The charcoal blast-furnaces are mostly of old construction, with thick rough walls of brick or stone. The blast is cold or insufficiently hot, and of low pressure. In Finland the furnaces are 30 to 35 feet in height, whilst in the Ural they are 50 feet and more. In 1890 there were 214 blast-furnaces, of which 69 were driven with cold blast. Of the pig iron produced, 37½ million

* *Stahl und Eisen*, vol. xiv. p. 145.

† *Berg- und Hüttenmännische Zeitung*, vol. liii. pp. 47-51.

poods was made with charcoal, $18\frac{1}{4}$ million poods with mineral fuel, and 1 million poods with mixed fuel.

Since 1870 the production of pig iron has increased $4\frac{1}{2}$ times.

Development of the Russian Mining Industry.—R. Helm-hacker* traces the development of the Russian mining industry from the beginning of the seventeenth century. In 1719 a mining department was inaugurated. Since that date the mining industry has made rapid progress, and at the present time more than one-fiftieth of the entire population of the empire is dependent on mining and metallurgy. The actual number of persons employed in mines and smelting works in 1890 amounted to 435,700. These are distributed over the various districts as follows:—

Ural	231,800
Central Russia	29,800
Poland	22,500
Southern Russia	69,000
Caucasus	17,600
Central Asia	200
Northern Russia	11,600
West Siberia	18,100
East Siberia	31,000
Finland	4,200

The Iron Trade of Finland.—The output of lake iron ores in Finland in 1891 amounted to 58,252 tons from 177 lakes. Of these 122, with an output of 38,760 tons of ore, were situate in Kuopio. The cost of mining and transport to the smelting works amounted to £11,500. The quantity of pig iron produced from 42,511 tons of this ore was 15,090 tons, showing a yield of about 35·5 per cent. The total quantity of iron ore produced was 58,692 tons; of pig iron, 23,074 tons; 4810 tons of weld iron; 14,281 tons of puddled iron; 11,251 of rolled iron; 3032 of open-hearth steel; 3867 of shaped iron; 6819 tons of castings; together with 770 tons of iron of other kinds.†

There were sixteen ironworks situated in six districts, and these possessed seventeen active blast-furnaces. The blast-furnaces of Western Finland smelted mostly Swedish ores, which yielded from 44·2 to 50·5 per cent. of iron, one ton of pig iron being produced at an expense of from 60 to 90 hektolitres of charcoal. Only one works, that at Mökö,

* *Berg- und Hüttenmännische Zeitung*, vol. liii. pp. 89-92.

† *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlii. pp. 26 and 36; *Stahl und Eisen*, vol. xiv. pp. 90-91.

had two blast-furnaces in blast. The temperature of the blast varied up to a maximum of 250°C., but five furnaces used cold blast. The high bloomery-furnace is still in use in Sweden, but under this heading are included furnaces of the Husgafvel type. One of these latter made 681·5 tons of blooms in 274 working days, from lake ores yielding 37·5 per cent. of iron, and consumed 229·6 cubic feet of charcoal for each ton of metal produced. These Husgafvel blooms were hammered out to wire rod billets. Details are also given as to the other forms of furnaces in use, as to the raw materials used in the works, and the iron trade products exported to Russia.

XI.—SPAIN.

Mineral Statistics.—Preliminary statistics * show that the output of iron ore in Spain in 1893 was slightly in excess of that of the previous year. From Bilbao 4,036,054 tons was exported in 1893, as compared with 3,918,544 tons in 1892. From three ports on the Cantabrian coast the quantity of ore exported in 1893 was about 295,000 tons, as compared with 320,000 tons in the previous year. The total output of iron ore in 1893 is estimated at about 5,500,000 tons, as compared with 5,405,142 tons in 1892.

The production of iron and steel was as follows :—

	Pig Iron.	Malleable Iron.	Steel.
	Metric Tons.	Metric Tons.	Metric Tons.
1892	247,329	122,295	56,490
1893	260,450	121,349	71,200

In the output both of iron ore and of iron and steel, Vizcaya is pre-eminent over the other provinces. In the output of iron ore Murcia, Santander, and Almeria are next in the order of their outputs, but as regards the furnace products the order after Vizcaya is Oviedo, and then, with almost equal outturns, Guipúzcoa, Navarre, and Alava, but these produce relatively small quantities of either iron or steel when compared with the provinces of Vizcaya and Oviedo.

The output of coal in Spain in 1893 is estimated at 1,532,000 tons, as compared with an output of 1,424,185 tons in 1892. More than half

* *Revista Minera*, vol. xlv. pp. 44 and 50-52.

the total output is obtained from the province of Oviedo, the next in importance being Cordova, Palencia, and Sevilla.

The output of lignite seems to have experienced a slight diminution, having fallen from 37,011 tons in 1892, to 34,100 tons in 1893. Much the largest output is shown by the province of Guipúzcoa.

Three years have elapsed since the Spanish Government has published official statistics relating to the actual mineral output of Spain, though estimates have been published from time to time by the *Revista Minera*. Other statistics have been published by the *Revue Universelle*, which contain the following statements of production relating to the year July 1, 1892, to June 30, 1893:—

Production of Minerals.

	Metric Tons.
Magnetic iron ore	35,996
Argentiferous iron ore	436
Total iron ore	5,389,604
Manganese ore	90
Coal	1,458,660
Brown coal	21,053
Briquettes	287,822
Coke	29,379

Production of Iron and Steel.

	Tons.
Pig iron	134,299
Bar iron	63,218
Steel	65,926
Wire	3,600

The total quantities of all kinds of minerals raised and of furnace products were respectively, 9,869,996 tons and 952,747 tons.

According to a report by the Belgian Consul-General at Bilbao, dated January 14, 1894, the exports of iron ore through the port of Bilbao amounted in 1893 to 4,064,800 tons. This total was exceeded only in 1887 and in 1890.

The executive commission on mineral statistics in Spain has been reorganised under the direction of F. de Botella. Its first publication, dealing with the economic year extending from July 1, 1891, to June 30, 1892, shows that there were in Spain 15,694 productive mines, of which 442 were collieries, and 268 iron mines.*

Production of Iron Ore in Cuba.—According to a recent report by the United States Consul at Santiago de Cuba, the principal iron

* *Board of Trade Journal*, vol. xvi. p. 211.

mines of Cuba are between Santiago and Guantanamo, along the south-eastern coast of the island, within a radius of 50 miles. Three American companies—the Juragua, the Sigua, and the Spanish American—have, in the aggregate, invested about £2,400,000 in plants to develop these mines. Several additional millions of American capital are invested in ships which transport the ore from Cuba to Baltimore, Philadelphia, Perth, Amboy, and New York.

During the year 1892 the amount of ore shipped from this consular district was 341,050 tons, and for the first six months of 1893 the amount was 273,000 tons.

The ore from the Cuban mines yields from 60 to 67 per cent. of iron, and manganese ore is also found in very large quantities in the same mountain range of Cuba in which the iron ore is found, within a distance of 75 miles. American enterprise has also asserted itself here by capturing the richest and most available mines. These mines are now being connected with the seaboard by short railways.

During 1892 there was shipped to the United States from this consular district 18,851 tons of manganese ore, and during the first six months of 1893 the amount transported was 11,640 tons.

With the rich deposits of the Ponupo and other mines recently discovered in Cuba, the completion of railroad connections with the coast, and the addition of improved machinery now being put up, those interested in the Cuban mines confidently assert their ability to undersell the Europeans in the American markets. The decreased price of manganese will make available many Pennsylvania iron mines which it does not pay to work at present.

XII.—SWEDEN.

Iron Ore.—A report of M. S. Constable, Her Majesty's Consul at Stockholm, dated the 16th February, has been received,* intimating that a largely increased output is now expected from the Falun mining district in the course of the present year. The output from the Grängesberg mine for 1893 amounted to 270,000 tons of iron ore. For the present year it will probably reach 350,000 tons.

* *Board of Trade Journal*, vol. xvi. p. 313.

XIII.—UNITED STATES.

Production of Pig Iron.—The total production of pig iron in the United States in 1893 * was 7,124,502 tons, as compared with 9,157,000 tons in 1892. The make of Bessemer pig iron in 1893 amounted to 3,568,598 tons. The production in 1893, according to the fuel used, was as follows :—

Fuel Used.	Blast-Furnaces.	Tons.
Anthracite	141	1,347,529
Charcoal	118	386,789
Bituminous coal	259	5,390,184
Totals	518	7,124,502

Production of Bessemer Ingots and Rails.—The following table † shows the production of Bessemer steel ingots in the United States in 1893 compared with that in 1892 :—

States.	1893.	1892.
	Tons.	Tons.
Pennsylvania	2,034,058	2,397,984
Illinois	314,829	897,952
Ohio	348,141	409,855
Other States	426,496	480,644
Totals	3,123,524	4,186,435

The total production of Bessemer steel rails in 1893, with the exception of the small quantities of rails made by other manufacturers from purchased materials, was 1,036,353 tons, a decrease of almost 29 per cent. as compared with the production in 1892.

Mineral Statistics.—The *Engineering and Mining Journal* has published the following statistics of mineral production in the United States in 1893 :—

	Tons.
Anthracite	48,044,834
Bituminous coal	113,847,568
Coke	9,792,230
Chrome ore	16,000
Manganese ore	9,150

* *Bulletin of the American Iron and Steel Association*, vol. xxviii. p. 22.

† *Ibid.*, p. 21.

In these returns the production of coke is expressed in short tons of 2000 lbs. The production of petroleum is stated to have amounted to 50,349,228 barrels of 42 gallons.

Production of Tin Plates.—According to a report to the Secretary of the Treasury by Ira Ayer,* for the year ending June 30, 1893, the total production of tin and terne plates in the United States was 99,819,202 lbs., compared with 13,646,719 lbs. for the preceding year.

Imports and Exports.—The report of the United States Bureau of Statistics for the year 1893 has recently been issued. The imports of iron and steel into the United States in the calendar years 1892 and 1893 are stated to have been as follows:—

Description.	1892.	1893.
	Tons.	Tons.
Iron ore	806,585	526,951
Pig iron	70,125	54,394
Scrap iron and steel	29,228	6,273
Bar iron	19,232	14,896
Bars, railway, of iron or steel	347	2,888
Hoops or band iron	1,011	1,697
Hoop, band, or scroll iron or steel	725	1,017
Ingots, blooms, slabs, billets, and bars of steel	30,586	26,868
Sheet, plate and taggers iron or steel	26,959	37,130
Tin plates, terne plates, and taggers tin	268,223	253,489
Wire rods of iron or steel	42,423	36,017
Wire and wire rope	3,831	4,145
Anvils	748	589
Chains	544	364

The exports during the same periods were as follows:—

Description.	1892.	1893
	Tons.	Tons.
Pig iron	15,427	24,670
Band, hoop, and scroll iron	36	255
Bar iron	963	1,842
Wheels	9,566	13,426
Ingots, bars, and rods of steel	205	358
Nails and spikes:—		
Cut	6,816	5,888
Wire, wrought, horseshoe, and others, including tacks	964	1,225
Wire	15,085	16,725
Plates and sheets:—		
Of iron	259	1,895
Of steel	202	585
Railroad bars or rails:—		
Of iron	486	164
Of steel	7,496	19,712

* *Board of Trade Journal*, vol. xvi. pp. 282-283.

Production of Natural Gas and Petroleum.—The value of natural gas consumed in the United States, as far as it can be ascertained, is given by J. D. Weeks * as follows :—

1887.	1888.	1889.	1890.	1891.	1892.
£3,173,500	£4,525,975	£4,221,219	£3,758,545	£3,100,017	£2,960,142

In 1885 the value was about one million, and in 1886 two million pounds.

The production of crude petroleum for 1892, as compared with that of the previous year, is given in barrels of 42 gallons as follows :—

	1892.	1891.
New York	1,273,843	1,585,030
Pennsylvania	27,149,034	31,424,206
West Virginia	3,810,086	2,406,218
Ohio	16,362,921	17,740,301
All States	50,509,186	54,291,980

The producing States not detailed above are Indiana, Kentucky, Missouri, Kansas, Colorado, California, Texas, and Indian Territory. The decrease in 1892 was 3,782,844 barrels. The value in 1891 was £6,105,310, as compared with £5,180,287 in 1892. The total production from the discovery of oil in 1859 to the end of 1892 has been nearly 559 million barrels, of which Pennsylvania and New York have contributed over 458 millions, and Ohio 80½ millions.

The total exports of crude and refined oil and residual products were 744,638,463 gallons in 1892, as compared with 673,805,703 gallons in 1891. The value in 1892 is given as £8,545,831. The low prices and enormous production of 1891 have had a great influence on the industry. A large number of statistics of the wells and other particulars of the different fields are given.

The Iron Industry of Colorado.—There is but little doubt that in time Colorado will become the centre of iron and steel production in the Western States. High-grade iron ores and good coking coals are found in close proximity to each other. An average analysis of the ore gave the following results :—

Iron.	Silica	Sulphur.	Phosphorus.
66·32	1·10	0·013	0·012

Descriptions of numerous large bodies of iron ore have been published

* *Mineral Resources of the United States*, Calendar Year 1892.

by R. Chauvenet,* and the Denver Steel Company estimate the cost of making pig iron in Gunnison county at 10 dollars a ton.

XIV.—COMPARATIVE TABLES.

The World's Production of Coal and Iron.—For the purposes of comparison, the following summary of the production of coal in the principal countries of the world is appended:—

Country.	Year.	Production in Tons.
United Kingdom	1893	164,325,795
Australia—		
New South Wales	1893	3,278,328
New Zealand	1892	673,315
Queensland	1892	265,086
Tasmania	1892	35,669
Victoria	1892	23,363
Austria, coal	1892	9,241,126
" lignite	1892	16,190,273
Hungary, coal	1891	994,812
" lignite	1890	2,249,098
Belgium	1893	19,407,254
Canada	1893	3,719,170
Cape of Good Hope	1892	41,717
France	1893	25,738,073
Germany, coal	1892	71,327,752
" lignite	1892	20,977,931
India	1892	2,537,696
Italy, lignite	1892	295,713
Japan	1890	2,608,285
Natal	1893	129,255
Russia	1892	6,225,413
Spain	1893	1,532,000
Sweden	1892	199,380
United States	1892	160,115,421

A similar summary showing the production of pig iron is as follows:—

Country.	Year.	Production in Tons.
United Kingdom	1893	6,829,841
Austria	1892	630,790
Hungary	1892	281,833
Belgium	1893	760,296
Canada	1892	51,000
France	1893	2,032,567
Germany	1893	4,953,148
Italy	1892	12,729
Japan	1890	16,176
Russia	1892	919,614
Spain	1893	260,450
Sweden	1892	485,664
United States	1893	7,124,502

* *Engineering and Mining Journal*, vol. lvii. p. 98.

Basic Steel.—The total make of steel and ingot iron from phosphoric pig iron during 1893 amounted to 3,638,556 tons, being an increase over the make for the previous twelve months of 435,916 tons. Of this the basic Bessemer output was 2,808,241 tons, and that of the basic open-hearth 830,315 tons. Of the steel containing under 0·17 per cent. of carbon, the basic Bessemer process produced 2,304,881 tons, and the basic open-hearth 596,716 tons.* With the steel, 874,000 tons of slag was produced, containing about 36 per cent. of phosphate of lime, nearly the whole of which was used as a fertiliser. The make of the various countries for the years ending December 31, 1893, and December 31, 1892, respectively, were as follows:—

Country.	1893.		1892.	
	Total.	With under 0·17 per Cent. C.	Total.	With under 0·17 per Cent. C.
United Kingdom	358,036	293,445	406,839	317,583
Germany and Luxemburg	2,344,754	1,971,441	2,013,484	1,616,783
Austria and Hungary	314,992	229,957	288,122	212,408
France	363,017	243,263	287,528	196,190
Belgium, Russia, and United States	257,757	163,491	206,667	129,028
Totals	3,638,556	2,901,597	3,202,640	2,471,992

• **Trade in Coal Briquettes.**—The export of coal briquettes † is yearly assuming greater importance.

In January, 1894, the total exports from all countries in the world reached 44,845 tons, as compared with 25,260 tons in January 1893, and 17,915 tons in January 1892. It thus appears that the exports in January exceed those of the corresponding period of 1893 by 19,585 tons, or more than 75 per cent., and that they are greater than in January 1892 by 26,930 tons, or about 160 per cent.

The total exports in 1893 were 491,938 tons, as compared with 351,570 tons in 1892. The figures for the principal countries were:—France, 228,250 tons; Switzerland, 71,529 tons; United States, 55,045 tons; Luxemburg, 35,685 tons; the Netherlands, 16,582 tons; Germany, 15,290 tons; England, 12,461 tons; and Spain, 11,940 tons.

The World's Consumption of Petroleum.—According to data obtained by the *Bulletin du Musée Commercial*, ‡ the world's consumption of petroleum is 58·30 per cent. for American petroleum, and 41·7 per cent. for Russian petroleum.

* Communicated by Mr. P. O. Gilchrist, F.R.S., February 21, 1894.

† *Moniteur des Intérêts Matériels*, vol. xliv. p. 559.

‡ January 20, 1894.

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